A. STERNFELD

INTER—PLANETARY TRAVEL

EARTH
VENUS
MERCURY
0.289 year
0.400 year
TRANSIT TIME
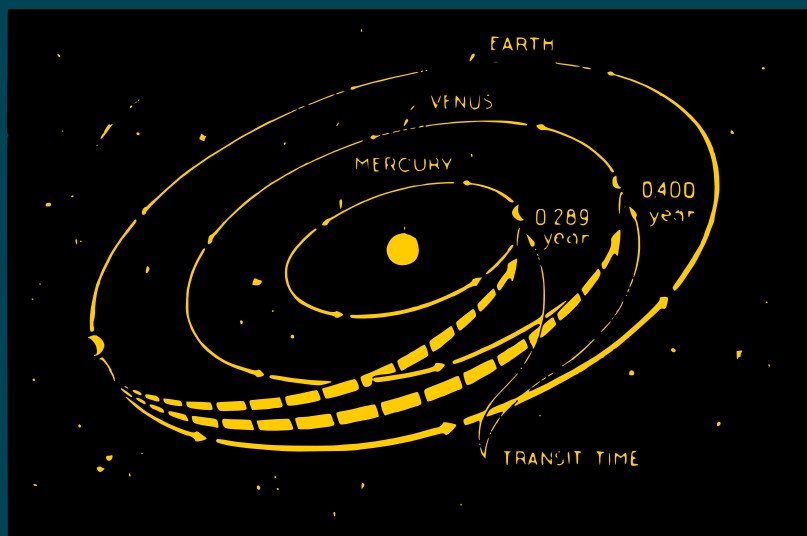
A. STERNFELD

*Winner of the International
Encouragement Prize in Astronautics*

INTERPLANETARY

TRAVEL

SECOND REVISED EDITION

А. ШТЕРНФЕЛЬД

МЕЖПЛАНЕТНЫЕ ПОЛЕТЫ

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INTRODUCTION

On October 4, 1957, the launching by the Soviet Union of the first man-made satellite ushered in the era of interplanetary flight so presciently prophesied by Tsiolkovsky at the turn of the century. A month later (November 3) the U.S.S.R. sent up its second satellite, this time with a test animal. On January 31, 1958, the U.S.A. established its first artificial satellite in orbit and in March it launched another two. On May 15, 1958, the third Soviet satellite weighing 1,327 kg began to circle the earth. Coming are trips around the Moon and our neighbouring planets—Mars, Venus, and Mercury—first using automatic remote-controlled probe rockets and then in manned rockets. Man will fly not only to other planets, their satellites, to comets, and to regions close to the Sun, but (in the more remote future) to distant stars.

The launching of the first artificial satellites of the Earth is a momentous victory of Soviet science and engineering in the peaceful competition of two systems—capitalism and socialism. This victory was achieved through the persistent efforts of a closely coordinated team of Soviet scientists, engineers, and technicians; it was the result of an unprecedented development of science and technology in the U.S.S.R. during the years of Soviet power.

Since 1924 there have appeared in the Soviet Union associations and societies whose aims are research into problems of reaction motion and interplanetary flight, and the combining of the endeavours of all persons interested in this branch of knowledge. In 1932, centres were established in Moscow and Leningrad to study and design reaction engines.

With a view to promoting research in astronautics, an interdepartmental Commission on Interplanetary Communications to coordinate the efforts of research institutes working on fundamental problems of space flight was established in 1954 as a part of the Astronomical Council of the U.S.S.R. Academy of Sciences.

In the same year, an Astronautical Section was established in the Central Air Club in Moscow. Different aspects of space flight are also studied in astronautical clubs that have been organized in the higher educational establishments of Moscow, Kiev, Kharkov, and other cities.

Until quite recently the problem of interplanetary travel was attacked from a purely theoretical angle. But now, when yesterday's dream has become reality with manmade celestial bodies girdling the Earth, some of the problems appear differently.

This book is based mainly on materials published earlier by the writer, but emphasis is placed on problems connected with artificial satellites, the launching of which has marked the first step on man's way into interplanetary space. Investigation of the Earth and the space surrounding it by means of artificial satellites is an integral part of the programme of the International Geophysical Year (July 1957-December 1958) —a scientific undertaking of extraordinary scope. All nations of the world, whose representatives meet annually at international astronautical congresses, participate in observing these mancreated moons. The International Astronautical Federa-

tion unites the national astronautical societies of over twenty countries, and has a growing membership. It is up to the peoples to decide to what degree their efforts be creative and not destructive so that the next steps into the cosmos will be seven-league.

A. STERNFELD

Moscow, February 1958

FROM LEGEND TO SCIENCE IN SPACE FLIGHT

Throughout the ages travel to other heavenly bodies has seemed a visionary dream. Legends have appeared in different periods about flights into outer space and about the Earth being visited by dwellers from other worlds.

Ancient Greek mythology has numerous legends on this theme. Everyone knows the Greek myth about Daedalus and Icarus who fashioned wings from feathers bound together with wax and flew from their prison in Crete. While over the sea, Icarus came so close to the Sun that the wax melted and he fell into the water.

There is another legend about the famous Greek commander Alexander the Great who tried to reach the heavens in a chariot drawn by eagles.

A Chinese legend relates that the Chinese arrived on Earth from the Moon. In the Indian epic *Ramayana* the hero travels through the heavens.

As man learned more of surrounding nature, legends gave way to scientific hypotheses. The first technical projects for establishing contact with other celestial bodies appeared in the 17th century. But in the light of present-day attainments they seem rather naive.

In *A Discourse Concerning a New World and Another Planet*, the English scientist John Wilkins refers to the feasibility of space flight on machines. A step further was made by the French writer Cyrano de Bergerac. Long before man had learned to fly he suggested the possibility of

using rockets for space travel. He even gave a description of a simple-type rocket ship.

Science-fiction novels devoted to interplanetary travel made their appearance in the 19th century. Jules Verne fired his heroes to the Moon from a gun.

Very popular at the beginning of this century were the science-fiction novels of Herbert Wells in England, and in Russia first those of A. Bogdanov, then later of A. Tolstoi and A. Belyaev, about inhabitants in other worlds.

Novels and stories about space flight were also written by scientists, and among them K. E. Tsiolkovsky.

*   *   *

In our age there has already appeared a science of space flight, called astronautics.* Modern astronautics is rooted in the remote past of many sciences, among which are astronomy and rocketry.

Copernicus demonstrated that the planets revolve about the Sun and not about the Earth, which itself revolves round the Sun. Kepler discovered the laws that govern the motions of the planets. Newton clearly defined the basic laws of celestial mechanics, the science of the movements of heavenly bodies. He suggested the possibility of a missile becoming a miniature "Moon," an artificial Earth satellite, and of sending a body from the Earth's surface into infinity.

The Copernican theory and the laws of Kepler and Newton are of cardinal importance in astronautics, for spaceships are something in the nature of celestial bodies, and, like the Moon, Earth, and other planets, they will follow very definite paths and be subject to these very same laws.

* From the Greek word *astron* star, and *nautikos* pertaining to ships. This is the same as cosmonautics *(cosmos* the world).

Surveying briefly the history of the rocket we find that in remote Chinese antiquity powder rockets were fired off on festive occasions, and in the Middle Ages, they were also used in warfare. At the end of the 16th century there already appeared descriptions and drawings of composite rockets, and in the middle of the 17th century the first sketches of rockets with stabilizing fins.

Russia's first acquaintance with the manufacture of rockets was at the beginning of the 17th century through the work of Onisim Mikhailov, a scribe. The first "Rocket Research Establishment" was founded in Russia in 1680. In the middle of last century it was headed by one of the biggest rocket authorities of pre-revolutionary Russia, K. I. Konstantinov, who introduced considerable refinements in the Russian war rocket. In 1881 N. I. Kibalchich designed a rocket-propelled flying machine.

The theory of rocket flight in interplanetary space was developed by K. E. Tsiolkovsky (1857-1935) who is called the father of astronautics. He was also the first to design a rocket propelled by liquid fuel. Among the more prominent of Tsiolkovsky's followers were F. A. Tsander (1887-1933) and Y. V. Kondratyuk (killed in 1942).

Much in the development of astronautics has been done by such pioneers of this science abroad as Robert Esnault-Pelterie (France), Hermann Oberth (Germany), Robert H. Goddard (U.S.A.), E. Sänger (Germany), by such popularizers and prominent men in astronautics as A. Ananoff (France), A. Haley (U.S.A.), Y. Stemmer (Switzerland), E. Burgess and A. Clarke (England), H. Gartmann (F.R.G.), and by interplanetary societies (American, British, German, and others).

* * *

It is often thought that nothing short of a revolution in technology is required to conquer the Solar System. This is not true. Man will push into interplanetary

space gradually, along with the development of technology.

Goddard's liquid-fuel rocket was sent up in 1926. The first Soviet liquid-fuel rocket (designed by M. K. Tikhonravov) was launched in 1933.

In the thirties, the altitude record for a simple-type liquid-fuel rocket was 13 kilometres, in 1952 it went up to 217 kilometres, and in 1955 it reached 288 kilometres.

Better results are obtained with the more complex composite-rockets: 400 km in 1949, nearly 500 km in 1953, and far over 1,000 km at present. Of course, this is still very little in comparison with distances to other worlds. The Moon is hundreds of times farther away, while the closest planet is tens of thousands of times more remote. Yet the attainments of rocket technology are very great.

The first Soviet artificial satellites of the Earth were launched in October and November 1957 and in May 1958. One step more is needed to increase the speed of the orbital rocket* one and a half times and it will throw off the shackles of the Earth's gravitation to fly to the closest heavenly bodies, the Moon, Venus, and Mars.

* This is a rocket capable of developing a speed sufficient for it to get into a circular or elliptical orbit, for instance, one that can become an artificial satellite of the Earth.

I. SPACE VEHICLES

1. Escape from the Earth

Take a look at our Solar System (Fig. 1) through whose expanses interplanetary ships will hurtle.

The Earth, one of the nine major planets of the Solar System, races along at a terrific speed in empty space
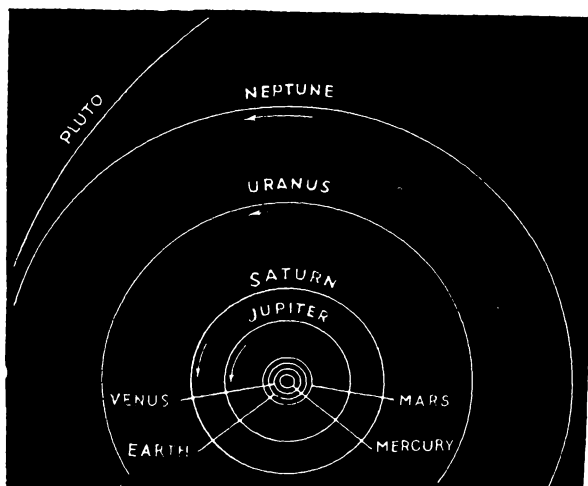

Fig. 1. The Solar System

sweeping out a nearly circular orbit around the Sun at a distance of about 150 million kilometres. This distance is taken as the astronomical unit. Nearly in the same plane

with the Earth's orbit are the orbits of the other eight major planets and a goodly number of the minor planets, or asteroids. Fig. 2 shows the relative proportions of the Sun, Moon, and planets.
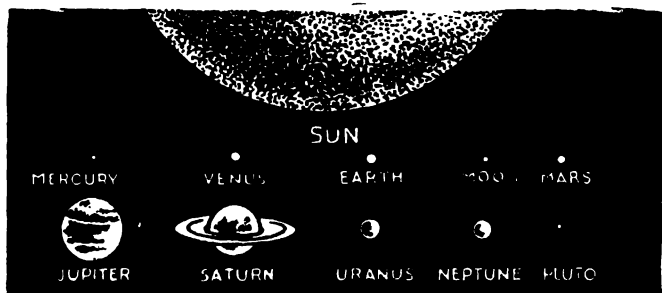
Fig. 2. Comparative dimensions of the Sun, Moon, and planets

Interplanetary space is bounded by the orbit of the farthermost planet—Pluto, which is some 6,000 million kilometres from the Sun. It is through these expanses of space that interplanetary ships will have to ply their way keeping wide of wandering meteoroids and swarms of asteroids, and either combating or utilizing the mighty pull of solar gravitation.

What have we to overcome in order to get out into space? First of all, the force of gravity. Everything on Earth is attracted to the centre. Not only the Earth but every single body (from the tiniest speck of dust to the mightiest star) possesses this property of matter, which we call gravitation. All the objects around us exert a gravitational force on each other, but since this force is infinitesimal we do not notice it. Yet the pull of the Earth is felt all the time.

Were it not for the force of gravity all objects would fly off the Earth into outer space. The Earth would recede

from the Sun, and the Moon from the Earth. But in space flight this attracting force is a handicap.

Can a rocket get away from the Earth and never return? The answer is yes. Imagine a mountain so high that the air no longer can interfere with the motion of the rocket. Picture then a horizontal launching site as shown in Fig. 3. A rocket launched at a definite speed would follow a high-arched course and fall a certain distance from
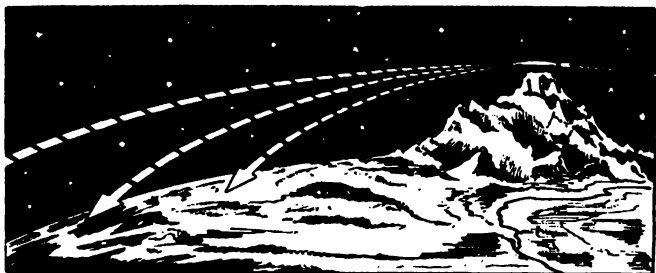
Fig. 3. Increasing speeds extend range of rocket and reduce curvature of its path. At circular velocity (upper orbit), the rocket moves parallel to the Earth's surface and becomes a satellite

the mountain. Double the speed and range and the trajectory becomes more gentle. Now the rocket may be given a speed such that the curvature of its trajectory coincides with that of the Earth's surface. In this case, it will go entirely around the Earth and then continue to circle it. Like the Moon, it will become a satellite never to fall back to Earth.

The minimum velocity at which a body begins to move round the Earth without falling back onto the surface is called the *first astronautical velocity* or *the circular velocity*.

The reason why a body moving at circular velocity does not fall back to Earth is this.

We know that when a body moves in a circle there arises a centrifugal force, which is the stronger the greater

the speed (it is proportional to the square of the velocity).
A person walking on a straight road develops a centrifu-
gal force of one milligram. A person running increases
this force several tens of times, while an airplane ripping
along at a speed of 2,800 km an hour produces a centri-
fugal force one per cent of the weight of the plane. And,
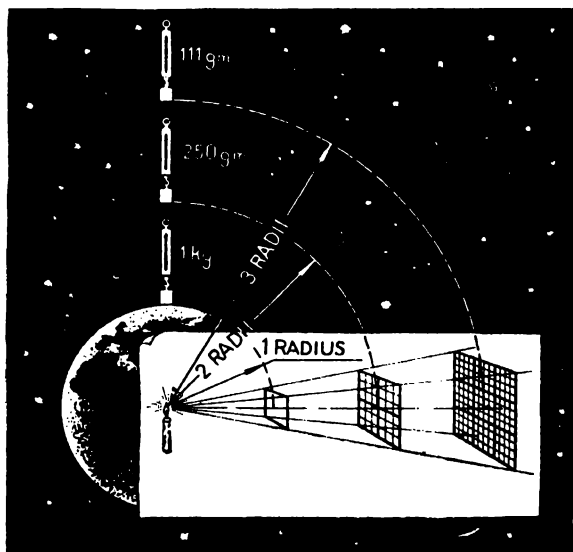
Fig. 4. Earth's gravitation falls off with dis-
tance exactly like the illumination of an object
receding from a source of light

finally, when the velocity is circular the centrifugal force
becomes equal to that of gravity thus seemingly elimi-
nating the action of the latter on the flying body (what oc-
curs, of course, is not the disappearance of gravitational
force; it is simply completely balanced by the centrifugal
force acting in the opposite direction). The body will cir-
cle the planet and in the vacuum of outer space its speed
will remain constant.

Now what speed must a body have to overcome the Earth's gravitation and recede into space?

To answer this question we must learn more about how the force of gravity acts.

The gravitational force of the Earth, like that of other heavenly bodies, falls off with increasing distance from its centre. It decreases just as rapidly as the illumination of an object with the light source receding, that is, inversely as the square of the distance (Fig. 4). In other words, when the distance from the Earth's centre is doubled, the force of gravity diminishes by a factor of four; if it is trebled, the effect will be nine times less, etc.

To free a body from the attraction of a planet, work has to be done sufficient to raise this body to a height equal to the radius of the planet, if we assume that the force of gravity does not change with the distance of the body from the centre of the planet. This energy may be imparted to a body by giving it a definite speed near the Earth's surface. At this speed, the body would describe a parabola (Fig. 5). Hence, the name of this velocity: *parabolic veloc-*
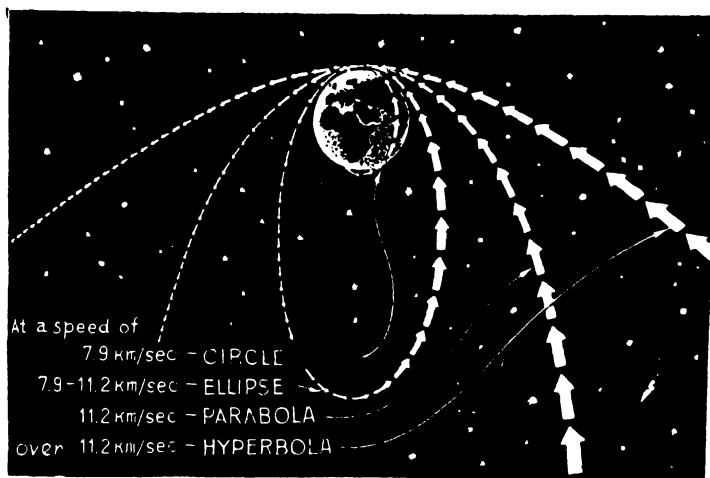

At a speed of
7.9 км/sec – CIRCLE
7.9–11.2 км/sec – ELLIPSE
11.2 км/sec – PARABOLA
over 11.2 км/sec – HYPERBOLA

Fig. 5. Flight paths for spaceships

ity, or *second astronautical velocity*, or, often, *"velocity of escape."* At the Earth's surface it is 11.2 km per second.

If a body is given a speed greater than circular, but less than parabolic, it will move in an elliptical orbit. If the velocity exceeds parabolic, the body will describe a hyperbola (Fig. 5).

For the sake of simplicity we assume the body to be attracted by the Earth alone. In reality, it is also affected by the Sun's gravitation. Calculations show that a velocity of not less than 16.7 km per sec must be imparted to a body for the latter to overcome both terrestrial and solar attraction. *This is the third astronautical velocity.*

The first of these barriers (the first astronautical velocity) was cleared in the launching of the first artificial satellite of the Earth—Sputnik No. 1. Astronautics now faces the second astronautical velocity, to be followed by the third.

2. Rocket—Prototype of Spaceship

It is generally recognized at present that rockets will serve as the engines of interplanetary ships, which will be able to move in airless space since their thrust is provided by ejected gases. The motion of the rocket is no risk to the passengers for, in contrast to an artillery shell, a rocket gains speed gradually. At take-off the astronauts will withstand relatively small accelerative forces that are harmless.

Since the flight velocity in the atmosphere may be kept relatively low, a rocket ship will not experience any considerable air resistance, and frictional heating in the air will not be appreciable.

The rocket engine may be used to accelerate or decelerate the ship in the vacuum of outer space, or, when necessary, to change its course.

What is the principle behind rocket propulsion?

A thing of common experience is the recoil of a rifle. This is due to gases (produced when the gunpowder burns) which exert the same pressure both on the bullet and the gun. But since the mass of the gun is much greater than that of the bullet, the former recoils slowly. This phenomenon is explained by one of the basic laws of mechanics—the law of the equality of action and reaction. Motion which is produced by the force of reaction is called reaction motion.

The powder rockets of pyrotechnic displays are not suitable as motors for spaceships. This is due to the very high pressure produced as the powder burns. To withstand such a pressure, the rocket must be super-rigid and, consequently, very heavy. Besides, the consumption of powder during flight is no more controllable than the flame of a candle. The burning process cannot be stopped to turn off the engine in case of necessity.
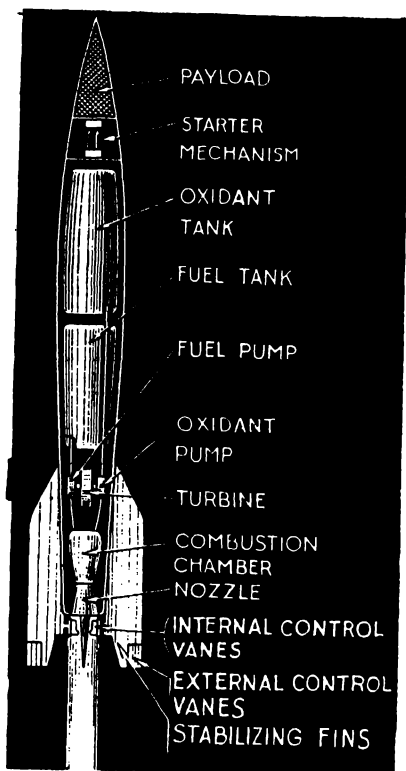
Fig. 6. A liquid-fuel rocket

These disadvantages are absent in the liquid-fuel rockets so widely used at present.

Reference to Fig. 6 shows that the liquid-fuel rocket has two tanks: one containing the fuel (for example, ethyl al-

cohol) and the other, an oxidant (say, liquid oxygen).

Two turbine-driven pumps gradually deliver both liquids to a special chamber where they react chemically, that is, the liquid fuel simply burns. The gases produced in this reaction blast out of the combustion chamber and thrust the rocket forward by recoil.

Stability in flight for both powder and liquid-fuel rockets is secured by the use of stabilizing fins and external control vanes.

But what happens when the rocket gets out into airless space, where the fins and external vanes will no longer be of any use to turn it back into its course if it strays away? This question was answered by Konstantin Tsiolkovsky, who suggested placing control vanes in the gas jet streaming out of the rocket. Such internal control vanes, or jet vanes, as they are called, can be used to change the course of the rocket in empty space. This can also be achieved by a brief change in the orientation of the engine relative to the rocket's axis of symmetry. To do this, the engine is not mounted rigidly to the rocket body but is hung in gimbals.

What factors affect the speed of a rocket?

In empty space, far from celestial bodies, a rocket moves the faster the more fuel it consumes and the greater the velocity of the gases being ejected (these values are related in an equation derived by Tsiolkovsky). For this reason fuels that produce the highest exhaust velocities, such as a combination of hydrogen and oxygen, are used.

But even in the liquid state hydrogen is light, requiring much larger tanks than other fuels. Besides, it boils already at a minus 253 degrees Centigrade. A more advantageous combination is hydrazine and nitric acid. These liquids are heavier than water, they may be contained in small tanks, and handling presents no difficulties.

Liquid-fuel rocket engines also use kerosene, petrol,

turpentine, paraffine, etc., with perchloric acid, hydrogen peroxide, and other fluids serving as oxidants.

Chemical fuels of this kind produce exhaust velocities of the order of 2.5 km per second but there are reasons for believing that it will be possible to push this velocity to four kilometres a second.

Fig. 7. A composite rocket

Another way of increasing the speed and "ceiling" of a rocket is to launch it by means of a booster rocket. When the latter has exhausted its fuel, it is automatically separated and let down by parachute. Then the main rocket is fired. At this point, it has already attained a certain height and velocity, which will enable it to climb higher than an ordinary rocket. A complex rocket of this type is called a composite, or stage, rocket (Fig. 7). By adding more stages (auxiliary rockets), it is possible to boost the speed and altitude (range).

To produce yet higher exhaust velocities, conventional fuels would have to be replaced by nuclear fuel. What is nuclear fuel and what advantages has it?

Physics has now successfully solved the problem of converting the chemical elements into one another. In certain cases these transmutations are accompanied by the release of nuclear (atomic) energy. A substance that releases energy of this kind is called a nuclear fuel, a distinguishing feature of which is that a small quantity of it contains a stupendous amount of energy.

Though nuclear energy is generated very rapidly, it is controllable. Atomic energy may be used to convert a liquid (such as liquid hydrogen or helium) into a gas and then expel the latter from the rocket. The working fluid is called the propellant, while the source of nuclear energy is the "fuel."

One should bear in mind that the term "nuclear fuel" should not be taken literally since the liberation of atomic energy is no ordinary process of combustion.

The principle behind the atomic rocket is this. Liquid hydrogen (or some other fluid) is fed to a small vessel that resembles the combustion chamber of the liquid-fuel rocket. The nuclear energy, generated in the form of heat, instantaneously heats the hydrogen to a very high temperature. The latter is converted to a gas, which emerges under a tremendous pressure. Atomic energy can eject gas jets at velocities of as much as several tens of kilometres per second. And the higher the exhaust velocity of the gases, the less fuel is required for the flight. Such is the huge advantage of an atomic rocket.

In principle, the atomic rocket is in no way essentially different from conventional rockets. But there are technical snags that stand in the way of building one. One has to "tame" the super-high temperatures and pressures which no metal can withstand. Another one is to protect humans from radioactive radiations, a concomitant of atom-power generation. This requires a material that is capable of absorbing these radiations and yet is not heavy because the slightest additional weight reduces the range of the rocket materially.

3. Artificial Satellites

The first man-made moon was a tiny structure indeed: a sphere 58 centimetres across weighing 83.6 kilograms (184 lbs) (Fig. 8). The body of the Sputnik was made of aluminium alloys and its surface was machined and

polished with extreme care so as to make it easily visible.

This satellite was equipped with one-watt radio transmitters operating on frequencies of 20.005 and 40.002 megacycles per second. Its four rod antennas were from 2.4 to 2.9 metres in length. When the orbital rocket was fired these antennas were flat against the body of the satellite. But after the satellite was released as an independent body, the antenna rods extended by means of joints to the position shown in Fig. 8. The antennas were the only parts on the outside of the satellite; all the instruments and power sources were inside the body. The hermetically sealed Sputnik was filled with nitrogen, which regulated heat exchange between the various instruments and components by means of constant forced circulation.

Fig. 8. First Soviet artificial Earth satellite—Sputnik No. 1 (photographed on a stand)

The second Soviet artificial satellite was the last stage of the carrier rocket with containers carrying the scientific instruments. The satellite had instruments for studying solar radiation in the short-wave, ultraviolet, and X-ray regions of the spectrum; instruments for the study of cosmic rays, temperature, and pressure; an air-tight container with a test animal (a dog); an air-conditioning
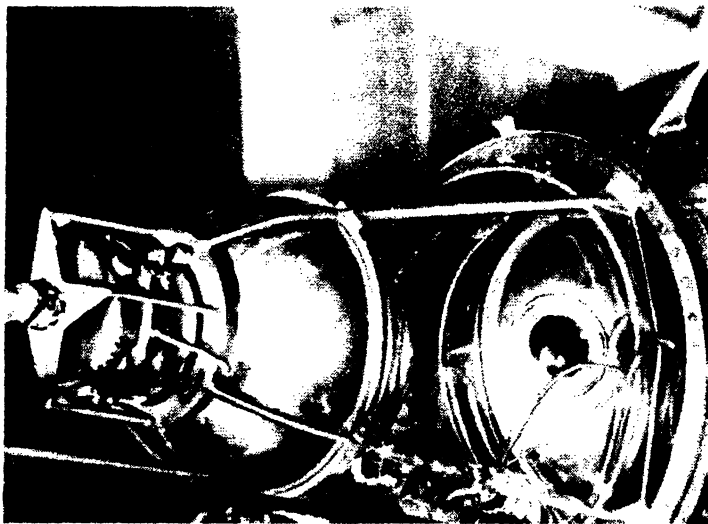
Fig. 9. Instrumentation
carried by the second
satellite

1 protective cone, jettisoned
after satellite is established in
its orbit; 2. instrument for
studying the ultraviolet and
X-ray regions of the solar
spectrum; 3. spherical con-
tainer with instrumentation
and radio transmitters; 4. in-
strument-supporting frame;
5. hermetically sealed cabin
with test animal
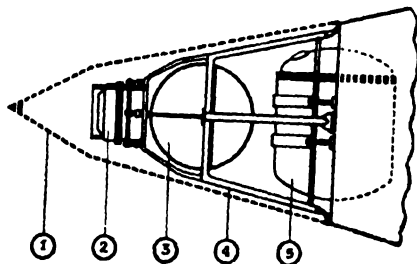
system; food; instruments for studying life processes in
conditions of cosmic space; measuring instruments; two
wireless transmitters operating on the same frequencies
as those of the first satellite (40.002 and 20.005 mega-
cycles per second); the necessary power sources.

The total weight of the instruments, the test animal, and
powers sources was 508.3 kilograms (1, 118 lbs).

The first American artificial satellite, "Explorer" I (scientifically known as Satellite 1958 Alpha 1), has the shape of a cylinder 15 centimetres (6 in.) in diameter, two metres (6.5 ft) long (this includes the 90 cm container), and weighs about 14 kilograms (31 lbs). It is the expended top stage of the orbital rocket (weight: 5.75 kg or 12.5 lbs) to which is attached a container with two radio transmitters and other instruments (weight: 8.22 kg or 18 lbs).

The third Soviet satellite is a big advancement over the first two. It weighs 1,327 kilograms, including 968 kilograms of scientific and measuring apparatus together with the power sources.

The satellite is conical in shape with a length of 3.57 metres and maximum diameter of 1.73 metres (this does not include the extended antennas). In it are installed numerous devices and systems for the conducting of complex scientific experiments, which are intended mainly to study phenomena that occur in the upper atmosphere and the effect of cosmic factors on processes in this region.

The satellite is equipped with electronic devices that give accurate measurements of its orbital motion, and with radiotelemetering apparatus for continuous registration of the results of measurements. The data are "memorized" and then telemetered to Earth when the satellite flies over special stations (on the territory of the U.S.S.R.) that receive the accumulated information. The satellite is provided with an all-semiconductor programme device that ensures automatic functioning of the scientific and measuring apparatus. All the other electronic devices too make extensive use of new semiconductor elements, the total number of which on board the satellite runs into several thousands. The power supply is electrochemical and from semiconductor silicon batteries that convert the energy of solar rays into electrical power.

The satellite is instrumented to conduct investigations, over the entire orbit, of: the pressure and composition of the upper layers of the atmosphere, the concentration of posi-

Table I

Order of launching	1	2	3	4	5	6
Name of satellite	Sputnik I	Sputnik II	Explorer I	Vanguard I	Explorer III	Sputnik III
Designation	Alpha 1957	Beta 1957	Alpha 1958	Beta 1958	Gamma 1958	Delta 1958
Date launched	Oct. 10, 1957	Nov. 3, 1957	Jan. 31, 1958	March 17.1958	March 26,1958	May 15,1958
Country in which satellite was launched	U.S.S.R.	U.S.S.R.	U.S.A.	U.S.A.	U.S.A.	U.S.S.R.
Weight (kilograms)	83.600	508.300	13.860	1.475	14.170	1327
Shape	spherical	oval	cylindrical	spherical	cylindrical	conical
Dimensions (cm)	Diam. 58.3	—	Height 203 Diam. 15	Diam. 16.25	Height 203 Diam. 15	Height 357 Max. Diam. 173
Period (minutes)	96.17	103.74	114.95	134	115.9	105.95
Angle of inclination of orbit to plane of equator	65°12'	65°17'	33.58°	34.1°	36.5°	65°
Perigee (kilometres)	227	225	350	650	187	—
Apogee (kilometres)	947	1.671	2,530	3,968	2.785	1.880
Velocity at perigee (metres per second)			8,225	8,234	8,382	
Velocity at apogee (metres per second)			6,196	5,583	5,978	
Type of rocket			4-stage	3-stage	4-stage	
Length of rocket (metres)			20.912	21.600		
Starting weight of rocket (tons)			29.500	10.250		
Total mechanical energy of satellite	100	633	18.1	2.1	17.9	1671

tive ions, the magnitude of the electric charge of the satellite and the intensity of the Earth's electrostatic field, the intensity of the Earth's magnetic field, the intensity of solar corpuscular radiation, the composition and variations of primary cosmic radiation, the distribution of photons and heavy nuclei in cosmic rays, studies of micrometeorites, and of temperatures, inside and on the skin of the satellite.

Table I gives a list of the principal characteristics of the first six artificial Earth satellites. The last line is a comparison of the energies that the satellites possessed when established in orbit. The launching energy is considerably greater.

As we shall see further on automatic artificial satellites of this kind will be used to solve a large range of problems (both scientific and practical) of prime importance. The dimensions and designs of these satellites will be extremely varied.
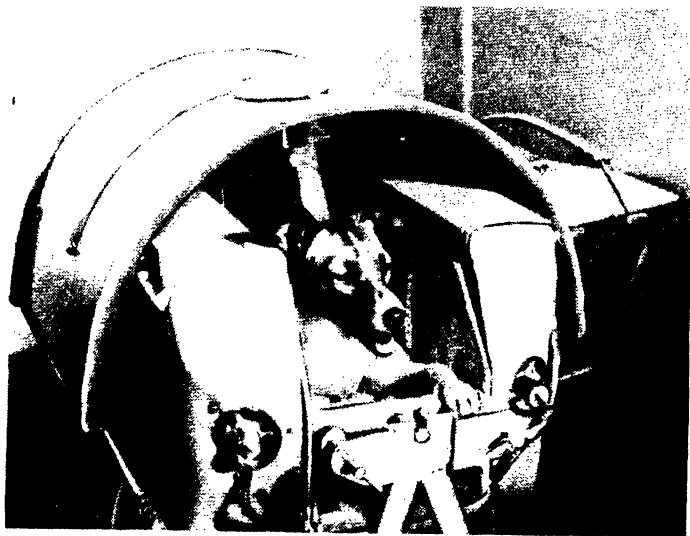
Fig. 10. The dog "Laika" in its cabin before being put into Sputnik No. 2
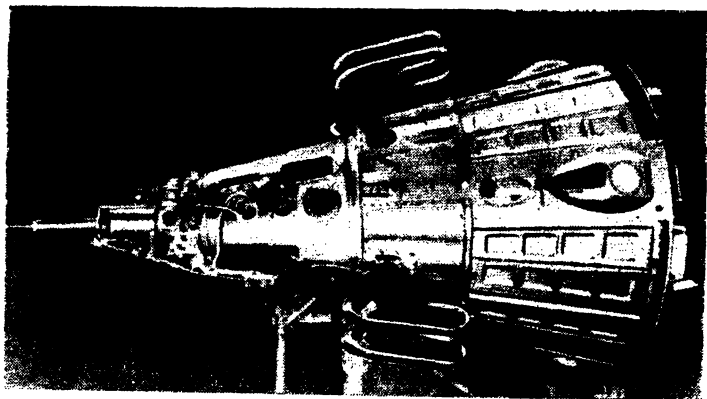
Fig. 11. General view of third Soviet artificial satellite of the Earth
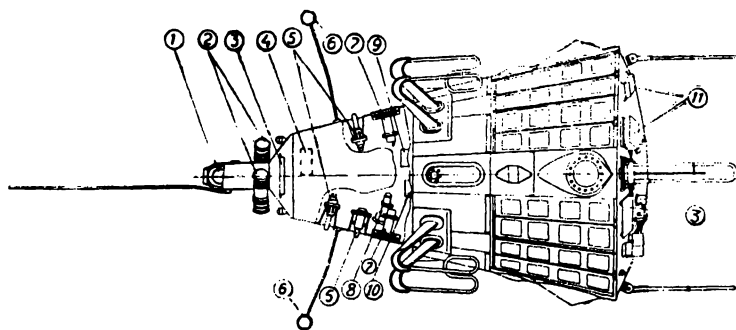
Fig. 12. Instrumentation of third Soviet artificial Earth satellite

1. Magnetometer. 2. Photomultipliers for registration of corpuscular solar radiation. 3. Solar batteries. 4. Instrument for registration of photons in cosmic rays. 5. Magnetic and ionization pressure gauges. 6. Ion traps. 7. Electrostatic fluxmeters. 8. Mass-spectrometric tube. 9. Instrument for registration of heavy nuclei in cosmic rays. 10. Instrument for measuring intensity of primary cosmic radiation. 11. Primary elements for registration of micrometeorites.

The electronic circuits, radio-measuring systems, automatic timer, and electrochemical power sources are installed inside the body of the satellite.

In time there will undoubtedly be established whole fly-ing observatories and interplanetary space stations.

There are still many difficulties on the way to produc-ing an inhabitable artificial satellite. And the biggest one is to get the crew back to Earth. This problem involves greater difficulties than that of launching the satellite. For this reason alone it is impossible at present to build an inhabitable satellite. However, the experience which will be gained in launching and operating the first automatic ar-tificial satellites will serve as a basis for subsequent con-struction of inhabitable satellites.

The outlines of big artificial satellites are as yet not fully worked out, but one thing is absolutely clear: the designers will not have to make them streamline. Since the resistance of a medium that could impede the motion of the satellite will be absent, the vehicle may be given any shape. For example, it may have the shape of a tore,* a huge hollow ring inside which all the necessary living and working conditions will be created. The outside walls of the structure may have handles, grips, and also decks and other contrivances necessary for mooring and assembling space rockets.

The cabins will not be very spacious since the builders of satellite vehicles are forced to cut down on weight and, hence, also somewhat on volume.

If the "doughnut" is made up of separate "cars" linked together by elastic vestibules, it will be an easy thing to extend it by inserting new "cars."

The cabins of the satellite will, of course, have to be hermetically sealed. The inside vestibules, doors, and par-titions will make the different rooms air-tight and the hatches will have to close by means of locking devices with elastic spacers. Entrance doors, framed for example with rubber, will open inside and not outside. In this way the

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* A tore is a solid of revolution in the shape of an automobile tyre.

pressure of the microatmosphere* will help to keep the doors tightly shut against the vacuum outside. The skin of the satellite will have to be continuous, without seams. Contact between the metal framework and the window-panes will be especially tight. The panes will be made of nonbreakable glass and will have roughly the same coefficient of heat expansion as the metal into which they are fitted or soldered.

Gas leakage from the cabins of the spaceship is of no great consequence in brief flights during which the foul microatmosphere has to be let out into space anyway and replaced by new air. However, it is not at all desirable to have gas let out in the case of an uninterrupted purification of the microatmosphere, which will be the rule during extended flights or in the cabins of permanent artificial satellites.

The Sun's ultraviolet rays, which traverse interplanetary space and in large quantities have an adverse effect on the human organism, will be stopped by the glass and skin of the artificial satellite in much the same way that the Earth's atmosphere does this job. If necessary, it will also be possible to draw special curtains over the windows. It may happen that due to meteor hazards and harmful radiations, the compartments of the artificial satellite will not be provided with windows facing outer space directly, in which case light rays will be brought in through narrow channels by a system of lenses and mirrors. Observations would then be conducted by means of periscopes similar to those used on submarines.

Proposals have been advanced for making artificial satellites in the shape of an air-filled "doughnut" made of rubberized material or a glass fabric or an impenetrable nylon-plastic fabric. But there is not much chance of finding a material capable of protection from cosmic rays (see p. 53 concerning harmful radiations). It is more prob-

* The microatmosphere is the air in the cabin of a space vehicle.

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able that the outer skin will be made of several layers of different materials.

As has already been pointed out, the Earth's gravitational pull will be balanced by the centrifugal force of the orbiting satellite. This will result in the objects and people on the satellite becoming weightless. In exactly the same way, we on Earth do not feel the attraction of the Sun but only that of the Earth. This is due to the terrific orbital speed of our planet. And the force of gravity of the satellite itself will not be felt because its mass is so small.

A satellite can be built to produce its own artificial gravity. By rotating it about its own axis we can create a centrifugal force which will take the place of the force of gravity (p. 48). It is also possible to build a composite satellite: on one part of such a structure everything would be weightless, while on the other part artificial gravitation would be produced.

Fig. 13 shows such an arrangement with rotating cabins that have artificial gravity. Basically, the satellite is assembled from tanks and other parts of the final stages of orbital rockets. This satellite scheme makes it possible to enlarge the structure indefinitely.

The satellite will of course have no lack of solar energy. Tsiolkovsky suggested trapping and utilizing these colossal solar streams to grow, in extraterrestrial "greenhouses," plants that the inhabitants of the celestial island could use as food. This would at one stroke solve the problem of a natural air cycle. However, such a greenhouse would have to have enormous proportions. If the only purpose of the greenhouse was to refreshen the air by growing inedible plants, it might be possible to reduce its area. But even so it would be a huge structure. Thus, for example, 28 sq. metres of leaf surface of the light-loving catalpa tree well exposed to the Sun's rays is required for the constant regeneration of one "portion" of air for a single person. For purposes of regenerating the microatmosphere, it would be found advantageous to use chlorella, an alga, which in the

Sun's rays produces in one hour enough oxygen to fill 50 times its volume. However, since the plants can wither, one cannot rely entirely on a natural cycle of air and water, and therefore an inhabited satellite will have to have an automatic air-conditioning plant.

At the beginning of 1956, Romick (U.S.A.) suggested the building of an artificial satellite to accommodate a whole city of 20,000 inhabitants. As far as one can judge
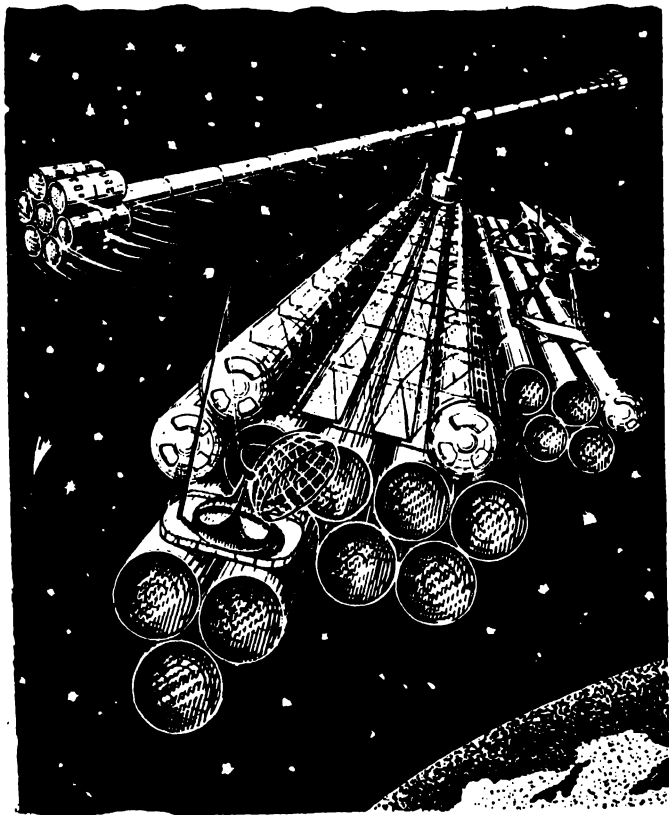

Fig. 13. One version of an artificial satellite. Lower part is in zero-gravity state, while upper part, due to rotational motion, has artificial gravity

from published articles, Romick's project is based on data that have frequently appeared in astronautical literature and does not contain anything to make it unfeasible. As regards the size of a satellite to accommodate 20,000 persons, it must be pointed out that proportions have nothing to do with the feasibility of the project: if a satellite can be built for 100 persons, it can be built for 1,000 and for 20,000 persons. The only questionable thing is: do we have any practical need for such a big satellite? It may be that by naming 20,000 as the population of the space island, the author of the project hoped thus to find a way to the hearts and minds of his compatriots. We on our part can only rejoice in the fact that the idea of the "father of astronautics," Tsiolkovsky, about building in outer space whole "cities" with artificial gravity continues to fecundate technical thought.

4. Assembling the Satellite

The building of large artificial satellites, and later, stations on the Moon and the planets will demand radically new assembling techniques.

Let us picture a rocket launched with a circular velocity and large enough to contain the living quarters, laboratories, workshops, storehouses, docking facilities for spaceships, and so forth. This would be an artificial satellite in the shape of a flying observatory or space platform for cosmonauts en route to the Moon or planets. The building of a large artificial satellite will probably proceed as follows. Some time after the first rocket has been launched, a second will be sent up and by radio-control will pull up alongside the first one. This will be followed by a third, fourth, and other rockets launched in the same way. At last a celestial body will have been formed of sufficient proportions to accommodate men, supplies, mechanisms, and instruments.

In this connection it may be recalled that refuelling aircraft in flight has been common experience for a long time. Obviously, this experience will be utilized in the construc-

tion of artificial satellites, though the velocities and heights here are far greater. The position and velocity of an artificial satellite may be predicted with greater accuracy than those of an airplane, the route and speed of which depend on the weather and the engine. An artificial satellite, as we know, is in no way affected by meteorological conditions and moves with the engine off.

Y. V. Kondratyuk considered that "it would be desirable to project into interplanetary space by the rocket-artillery method the charge and all other things ... capable of withstanding accelerations of several thousand metres per second. If properly packed they would include everything except delicate instruments. Human beings, of course, would be sent up separately."

In short, an artificial satellite may first be constructed on the Earth and tested exhaustively as to its reliability and the possibility of creating on it living conditions necessary for the crew. It will then be disassembled and the components rocketed up into the predetermined orbit where they will be reassembled.

Naval experience may be drawn upon to facilitate the docking of ferrying rockets. Mooring ropes (for example, a chain rope) may be thrown from the satellite to the rocket to enable the vehicles to pull up close to one another.

Another possibility is this. Instead of sending up rockets one by one to the satellite under construction, they could be sent up together like a squadron. This would obviate difficulties involved in individual rockets locating earlier launched rockets; and the satellite could be assembled much sooner since it would not be necessary to wait for different parts to be ferried up from the Earth. This in turn would reduce meteor hazards for the assembly crews (see p. 50).

5. Space Craft in Design

The type of spaceship depends on its designation. A ship for landing on the Moon will differ markedly from one designed for circumnavigation of the Moon; an Earth-to-
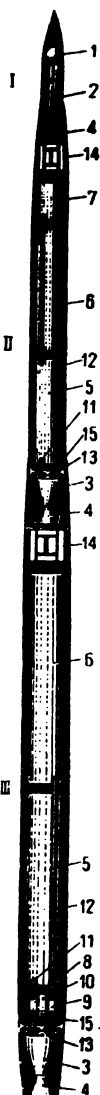
Mars ship will be quite unlike one leaving for Venus; and a chemically-propelled rocket will hardly resemble an atomic vehicle.

A chemically-powered spaceship designed for ferrying between the Earth and an artificial satellite will be a multistage rocket the size of a dirigible. At take-off, a rocket of this type with a payload of one ton should weigh a few hundred tons. The different stages will be tightly fitting and will be enclosed in a stream-line hull to reduce air drag. The relatively small cabin for the crew and the container for the payload will probably be housed in the nose of the ship. Since the crew will have to spend only a short time (less than one hour) on board this ship, there will be no need for the complex equipment of the interplanetary ships designed for protracted flights. Flight control and all measurements will be automatic.

The spent stages of the rocket will return to Earth either by parachute or on retractile wings that convert the stage into a glider.

A simple-type orbital rocket is shown in Fig. 14.

Let us examine another type of spaceship (see Fig. 11, centre, p. 27). The ship is to leave an artificial satellite on a circumlunar voyage to make a long-time exploration of the surface without landing. After fulfilling its mission it will return straight to the Earth. Its main parts, as may be seen from the drawing, are two twin rockets with three pairs of cylindrical tanks

Fig. 14. Possible design of an orbital rocket:
I.—Top stage of rocket, II—Middle stage, III—Bottom stage; 1. artificial satellite; 2. powder blocks; 3. combustion chamber; 4. nozzle; 5. fuel tank; 6. oxidant tank; 7. tank with compressed gas for feeding fuel into combustion chamber; 8. fuel pump; 9. oxidant pump; 10. turbine; 11. fuel pipeline; 12. oxidant pipeline; 13. gimbals for engine; 14. automatic pilot; 15. levers of automatic pilot for turning engine.

filled with fuel and oxidant, and two space gliders with retractile wings for descent through the Earth's atmosphere to the surface. The ship does not need any streamline fairings since it will be launched from beyond the atmosphere.

Such a ship will be fully built and tested on the Earth, and then rocketed out to the space station piecemeal. Fuel, equipment, provisions, and oxygen will be ferried up separately.

After the ship has been reassembled at the interplanetary base, it will take off into space.

The fuel and oxidant will be fed to the engine from central cylindrical tanks which serve as the main cabins of the spaceship temporarily filled with fuel. These tanks empty in just a few minutes after take-off and meanwhile the crew will occupy the less comfortable cabin of the glider.

When the ship approaches the Moon it becomes an artificial lunar sub-satellite. For this purpose, use is made of the fuel and oxidant in the lateral rear tanks. After the fuel is exhausted the tanks are detached. When the time comes for the astronauts to return to Earth, they will turn on the engine again. Fuel for this purpose is stored in the lateral front tanks. Before entering the Earth's atmosphere the crew transfers to the space gliders that separate from the remainder of the ship, which continues to circle the Earth. The glider enters the terrestrial atmosphere and glides down on its extended wings.

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In one respect, a space vehicle (say, an artificial satellite) resembles a submarine: in both cases the crew has to live in a hermetically sealed cabin completely isolated from the medium outside. The composition, pressure, temperature, and humidity of the air inside the cabin will be regulated by special devices. But the advantage of the spaceship

over that of a submarine is that the former will have a smaller difference of pressure between the inside and the outside cabin. For the spaceship, this difference is only one atmosphere (outside, the pressure is zero), while for a submarine it is often several atmospheres.

The problem of maintaining requisite pressure in the cabin of the spaceship is vitally important. It may be that given definite proportions of air components, astronauts will be able to breathe when the pressure in the cabin is below one atmosphere. And the less the pressure in the cabin of the artificial satellite, the thinner the walls and the simpler the design of cabin and spacesuits and the less the danger of an air leak into outer space at weak joints in the hull or through holes produced in the hull by meteors.

In the terrestrial atmosphere, oxygen deficiency is usually felt at a pressure of 430 mm of mercury, which corresponds to an altitude of 4.5 kilometres above sea level. Experiments have demonstrated that air inhaled at reduced pressure must have a higher oxygen content to prevent asphyxia.

At gas pressure below 47 mm of mercury, the human organism (and any other organism, for that matter) cannot exist even in pure oxygen, because at this pressure (it corresponds to an altitude of 19 km) the water in the body (37 degrees Centigrade) begins to boil. This is, of course, a real danger: the skin and cells break, and aeroembolism develops. At low pressure, hearing becomes faulty and the teeth ache. At the same time, to cut evaporation from the surface of the body, a higher pressure is required. The problem of optimum pressure can only be resolved by experiment.

The microatmosphere inside a spaceship should not consist of pure (or almost pure) oxygen.

Experiments have demonstrated that pure oxygen at 190 mm mercury produces the same physiological reactions as air at sea level. However, if pure oxygen is inhaled for a long time it weakens the organism.

Note also that with large quantities of oxygen, the fire hazard is greater and foodstuffs oxidize and spoil quickly; for this reason the microatmosphere should also contain other gases. In this connection the possibility has often been discussed of replacing the nitrogen of the microatmosphere of a spaceship or artificial satellite by one of the inert gases.

The air in the cabin can be continuously purified by cooling it in a special condenser to the temperature of liquefaction of carbon dioxide, that is, to minus 78 degrees Centigrade. First the water and then the liquid carbon dioxide will settle. To the purified air must be added the necessary quantities of oxygen and water vapour. Note that the water content in the microatmosphere should diminish as a result. After this the mixture should be heated to normal temperature.

It seems hardly expedient to ferry up to the artificial satellite for short-time service cumbersome equipment for renewing the air. It is apparently simpler to get rid of the foul air and bring in fresh by "airing out" the cabin. Carbon dioxide can be taken out of the microatmosphere by using chemicals. Thus, in a submerged submarine absorbers eliminate the carbon dioxide over periods of many days.

The necessary supply of oxygen can conveniently be taken along in liquid form. Oxygen can be ferried up from the Earth to the artificial satellite even as a solid which will require the very lightest container. Oxygen for breathing may also be stored in sodium peroxide, which absorbs carbon dioxide and excess moisture, and gives up oxygen. Hydrogen peroxide as a solid would be still more suitable.

In the gravity-free conditions that obtain in the microatmosphere of the artificial satellite, convection (air exchange between the lower and upper layers) is absent. One of the things this can lead to is asphyxia: the air becomes stagnant and carbon dioxide traps form which make breath-

ing and burning impossible. For this reason, ventilators or other means must be used to keep the air constantly mixed and at the same time to effect a unilateral forced circulation of the air.

II. MAN IN OUTER SPACE

1. High Speeds Are Harmless

Now let us examine the question of whether a human being will be able to stand up to the physiological phenomena associated with flights into outer space, say, to an artificial satellite, a stay on it, and a subsequent descent to the Earth's surface.

During such a cosmic flight, malaise may be caused chiefly by disturbance of the normal sensation of gravity. The first thing to note is that there is no velocity which the human organism cannot withstand, the only prerequisite being that it is not accompanied by too great an acceleration. Indeed, are we in the slightest degree disturbed by the rotation of the Earth on its axis? Yet a point on the equator is moving at 1,675 kilometres per hour due to the Earth's rotation. Or do we feel anything out of the ordinary as the Earth revolves about the Sun at a speed upwards of 100,000 kilometres per hour? And, finally, does the motion of our whole Solar System in space affect anyone as it races along at 70,000 kilometres an hour? The conclusion from these facts is that the human frame is capable of withstanding any speed.

A cosmic flight from the Earth is like a gigantic jump into outer space. During this jump, astronauts will at times have to withstand forces several times that of gravity, yet at other times they will be weightless. Similar are the phenomena that we observe in ordinary high jumps or broad jumps. When we push off the ground we feel the added weight of our body. This part of the jump is analogous to the take-off of a rocket from the Earth's surface. From the instant

one's feet leave the ground his body flies a certain distance under its own momentum and there is no sensation of weight. This part of the jump is much like the motion of a rocket ship with engine off. When, finally, his feet again touch the ground, his speed will fall off and he will again feel his weight. This third part of the jump resembles the braking period of descent to the Earth.

2. In the World of Overweight

When a railway train jerks into motion the passengers experience a push backwards, and if they are seated they will press up against the back of the seat. This is the so-called "gravities" (G's) whose source is acceleration. The effect of acceleration on the organism is absolutely identical with that of gravity. It is precisely this acceleration produced by the thrust of the rocket engine which will be felt by the space traveller in the rocket cabin. At take-off this force is naturally greater than the Earth's gravitational pull, otherwise the rocket would not move. This is why it became known as "gravities." One speaks of 3 G's, 5 G's, etc., which means 3, 5, etc., times the ordinary gravitational attraction at the Earth's surface.

When an airplane is catapulted into the air, the pilot experiences an acceleration of 4 G's, that is, he feels four times heavier than usual. In stunt flying, pilots often withstand 8 G's, while at swimming contests it is customary for divers to experience 16 G's when they go under. One should, however, bear in mind that on a catapult the acceleration lasts only a few seconds, and in diving into water (rather during the deceleration in the water after the fall) it is a mere fraction of a second. It is also a well-known fact that in ordinary transportation vehicles, speed may be built up over a long period of time if the acceleration rate is small. The foregoing examples are, however, in no way proof that a human being can withstand for a long period of time the acceleration necessary for attaining circular velocity.

Is it possible, before a space flight, to determine what acceleration a person can tolerate without endangering his life and for how long?

The centrifugal force produced in rotational motion causes accelerative forces too. In this way it is possible to obtain any magnitude of acceleration for long periods of time. The man is placed in the cabin of a rotating machine, a sort of whirligig that is made to move at a very high speed. By selecting the proper radius and speed of rotation, it is possible to produce exactly the same sensation as in a given rocket at take-off. The results obtained by such an experiment show that the crew of a rocket could withstand the higher accelerations that will be associated with the acquisition of astronautical velocities: an acceleration rate of 4 to 5 G's in the course of several minutes is harmless to the majority of people.

What a person is able to stand in the way of acceleration depends very essentially on the attitude of his body when the engine is working. For example, a person reacts differently to acceleration when lying face downwards or on his back and when in a sitting position. In a standing position, a person feels the greatest weight in his feet. In other attitudes, the sensation of weight and also the general fatigue of the body will differ. Thus, we get less tired sitting than when standing, and still less when lying down. The most effective way to reduce fatigue under acceleration is to put the person in a special, individual close-fitting capsule.* Experiments have shown that special-type "anti-gravity" suits (or, simply, g-suits) which provide extra pressure around the feet and lower part of the body to retard the blood flow from the head and simplify blood supply to the brain, enable a person to withstand an acceleration of 3 G's for a time period that exceeds that during which the engine of an orbital rocket is in operation.

* This suggestion was made by the author in 1933 in a paper presented to the Astronautics Committee in Paris.

Note too that the ability to stand up against high accelerations depends on the individual peculiarities of the body and, in part, on training. Accelerations that some withstand with relative ease are fatal to others.

3. Life in Conditions of Weightlessness

It is quite natural that people travelling in a rocket moving through space under its own momentum should feel weightless. The sensation of weight is the result of the pressure of a support (a floor, chair, bed, etc.) upon the body, as well as the mutual pressure the different parts of the body exercise upon each other. If the support is taken away the sensation of weight is lost too.

Here is an example. If we place three bricks one on top of the other the uppermost brick will exercise a certain pressure on the one in the middle, while the latter's pressure on the lowest brick will be twice as great. If we throw the three bricks out of the window, however, they will no longer press upon each other, none of them being a support for either of the others.

In astronautical literature, "weight" is usually taken to be the force which presses the objects and people in the spaceship cabin to the floor, and not the Earth's gravitational pull which, naturally, never disappears. It is precisely this pressing force, and not the force of terrestrial attraction, that is felt by space travellers; this force stretches the scale spring and the plumb line. In empty space this force is due exclusively to the thrust of the rocket engine; while in air, to the combined effect of rocket-engine thrust and air drag. In its absence, objects do not press on to one another, and people do not feel themselves pressed to the floor, that is, they lose their weight.

The Human Organism in Conditions of Weightlessness. The effect of weightlessness on man has been studied in part during high-altitude flights in jet aircraft. In these experiments, the airplane reaches a considerable height

and at the instant of maximum speed in upward flight the engines are cut off. The plane then continues under its own momentum in the tenuous layers of the atmosphere like a thrown-up stone—it experiences only a very slight air drag. In these conditions, the force of gravity disappears almost entirely ("almost," since the medium still offers a certain resistance). In this way it is possible to produce a zero-gravity state in a jet plane for about one minute. Finally, the effect of weightlessness (true, not complete) on humans and animals may be studied during vertical fall of an aircraft or in a delayed parachute jump (till the parachute opens).

Experiments have shown that a sensation of weightlessness for one minute is harmless, although at the very first the person loses all control over his movements (they become very jerky).

At the Seventh International Astronautical Congress (1956), Dr. S. J. Gerathewohl (U.S.A.) reported on the results of a series of experiments to study the effect of short periods of weightlessness on sixteen human subjects who took part in special experimental flights carried out in 1955-1956.

Sensitivity to the physiological effects of weightlessness proved exceedingly divergent not only in the different subjects but even in one and the same person depending on the circumstances. Whereas many found the weightless sensation pleasant, others had unpleasant symptoms to varying degrees. Some experienced nausea, with aftereffects lasting many hours after landing. During the brief period of weightlessness, no pathological processes in blood circulation were observed. The effects of weightlessness depend, in large measure, on training and duration of stay in the weightless state. It is very risky to extrapolate the results of short periods of weightlessness to the possible effects of zero gravity over long periods of time.

As already said, the sensations of the subjects in gravity-free conditions were highly subjective.

Thus, a pilot aged 35 with a thousand flying hours in jet planes and subjected to the action of weightlessness over 200 times (mainly in the plane that he himself was piloting) reported that no effort was needed to move his extremities and muscular coordination was not in the least impaired. There was no difficulty in orienting the airplane with respect to the Earth's surface. The directions of "up" and "down" did not change. The zero-gravity state was pleasant to the pilot; he did not notice any unfavourable symptoms with respect to sight, hearing, or breathing in these conditions.

Gerathewohl quotes a 22-year-old pilot who had experienced the effects of zero gravity as describing his sensations in the following words: "Actually, I've never been so bloody comfortable in all my life; and I think that if I had my choice of places to relax, a weightless condition would be definitely it."

Another subject, aged 46, with a wealth of experience flying gliders, relates just the opposite. In the zero-gravity state he lost all conception of "up" and "down." Among the subjects that fell ill because of the effects of weightlessness were 20-year-old novices and pilots of thirty and over with from 1,000 to 1,500 flying hours behind them.

A near zero-gravity state has been experienced by mice, dogs, and monkeys for still longer periods (up to 3 and 4 minutes). In experiments conducted in the U.S.S.R. under the supervision of A. V. Pokrovsky, dogs were sent up to 110 kilometres. As the rocket fell back to Earth the dogs were catapulted out in hermetically sealed capsules: one at an altitude of 90-85 kilometres and the other at 50 to 35 kilometres. From a height of 4 kilometres they were floated down to Earth on parachutes. All nine test animals landed safely (three dogs did this twice). The motion pictures taken during the flight, the electrocardiograms, temperature measurements of the dogs, their pulses, etc., showed that, on the whole, animals can adapt themselves very well to zero-gravity conditions although they react to

this state in different ways depending on individual peculiarities.

Thus we see that brief periods of gravity-free conditions are harmless to the organism of humans; at least they have no ill effects on many people. However, journeys on an artificial satellite or spaceship may last many days or even weeks and months, and therefore we can as yet only conjecture as to the sensations of cosmonauts. Some investigators believe that under protracted conditions of zero gravity the heart will function normally since its activities are similar to the mechanical work of a pump with a closed cycle: the heart has only to overcome the friction of the blood against the walls of the vessels. However, this reasoning cannot be relied upon, for cardiac activity is intimately associated with the central nervous system.

Respiration under gravity-free conditions appears to be more complicated. For example, in short falls (such as parachute jumps) there is usually a stop in breathing. If travel in an artificial satellite (which due to absence of weight will give the sensation of falling) lasts a long time, it is possible that artificial breathing equipment will be needed.

One can eat without gravity because food passes by contractions of the muscles of the oesophagus, and liquids can be swallowed even when standing on one's head.

Under ordinary conditions, physiological processes take place regardless of the body position, whether it be standing, sitting, or lying down. Therefore, varying the attitude of the bodily organs relative to the direction of gravitation does not essentially affect their ability to function. Admittedly, it is very difficult to hold one's head below one's body for a long time. This indicates that when the body is in certain unusual positions, gravity produces an adverse effect on the organism. But this does not at all mean that gravity is necessary for other normal attitudes. Quite to the contrary, since the greater part of the physiological functions proceed under the action of muscular forces, osmotic processes (diffusion through semipermeable mem-

branes), and the like, we have every right to hope that weightlessness will not interfere appreciably in the functions of the organism.

Such are the results of studies of the effect of weightlessness on a living organism in terrestrial conditions. The launching of the second Soviet satellite with a test animal opened up utterly new possibilities of studying the adaptability of organisms to the zero-gravity world. Sputnik No. 2 provided the first experimental test of the action of prolonged weightlessness on a living being. This experiment has proved encouraging: the physiological conduct of the dog aboard the satellite in a specially equipped, hermetically sealed cabin was satisfactory not only during the initial hours, but even for the first several days.

This is grounds for believing that space travellers will not lose their self-control (at least at the beginning of the flight) with the sensation of losing weight and will be able during this time to create suitable living conditions on board the spaceship.

Working and Living Conditions at Zero Gravity. We now discuss the physical phenomena that will occur under gravity-free conditions in everyday life on an artificial satellite and which will naturally differ essentially from the terrestrial phenomena we are accustomed to.

Without gravity, "up" and "down" lose their ordinary meaning. An object let go of will not fall down, and "down" will by convention be called the direction towards the centre of the Earth. It will be possible to rest in any position. To walk will be out of the question, because one's feet will not produce any pressure on the floor, and therefore the friction needed for locomotion will be lacking. To move about inside an artificial satellite or spaceship one will have to pull himself up to the walls or to fixed objects and push away from them.

It should be pointed out that despite the fact that nothing in an artificial satellite will have weight, a definite force will have to be applied over a given period of time in order

to move a body, or, on the contrary, to stop it or at least slow it down. This is because bodies naturally will not lose their inertia, that intrinsic property of any mass.

An astronaut that wants to climb out of the satellite into space will obviously have to do so with an attached cable. He can take with him a massive object attached to a small rope and by throwing it out in some direction he himself will move in the opposite direction (this is because the centre of mass does not change its position if only internal forces are operative). The same effect may be produced by means of a tiny rocket or pistol, but these techniques are associated with an irretrievable loss of mass for the spaceman.

There will be no way of using ordinary furniture or tools, except by attaching each item to something. In preparing meals, the dishes will have to be covered and rotated by a centrifuge so that the contents will adhere to the walls. Electromagnetic devices will be very convenient to use since they should function efficiently in the absence of gravity.

A liquid poured out of a vessel will turn into a sphere due to the action of surface tension. Upon contact with a solid, the forces of adhesion may exceed those of surface tension and then the liquid will flow out over the surface of the body. In general, handling liquids will be rather inconvenient. The only way to wash will be by using a sponge or towel soaked in water. To empty a bottle it will be necessary literally to "pull out" the liquid, or to utilize the centrifugal effect by moving the bottle in a large arc, or, finally, to use a pump or rubber syringe.

If under zero-gravity conditions one tries to strike a match, the head will light, but the match will not burn. Neither will a candle or a gas jet. The explanation is this. In terrestrial conditions the products of combustion (hot gases) are light and as they rise (by convection) they give way to fresh oxygen which is necessary to maintain the flame. But in the absence of gravity the gases are not

lighter than the surrounding air. They will accumulate about the flame and stifle it. To keep a flame burning one will have to feed it with a steady jet of oxygen. More convenient, of course, will be the use of electrical heating appliances that do not require oxygen.

In gravity-free conditions, the dust in the air will not settle to the floor and other surfaces, and thus will become a health hazard. Electric filters may be used to fight dust. Spacesuits for astronauts will have to be made so that they hold to their bodies regardless of gravity. Thus, control of many phenomena and functions on a space vehicle will entail difficulties. On the other hand, some operations (for instance, moving massive objects) will be simplified in the weightless state.

One important remark remains to be made. We sometimes hear of the "apparent" increase in weight or the "apparent" loss of weight on a rocket in flight. Such a view is fundamentally erroneous: the increase and loss of weight is an absolutely real thing and may be established with the aid of instruments.

Fig. 15. Change of weight in space flight

Fig. 15 shows how the weight of a body varies during a trip into space. On Earth the one kilogram weight suspended from a spring balance deflects the pointer to "one kilogram." But at take-off the weight of the "kilogram,"

just like that of all bodies on the rocket, increases sev-
eralfold, say fourfold, and the pointer indicates 4 kilo-
grams. During coasting flight all objects on the space-
ship lose weight and the pointer falls back to "0."

4. Artificial Gravity

In short, we do not yet have experimental proof that a
human being will in every respect feel normal in gravity-
free conditions. It may be that special medical means will
be required to maintain the normal functioning of the hu-
man machine.

Fig. 16. Creating arti-
ficial gravity on a
space vehicle

At first sight, the simplest thing
would be to create an artificial field
of gravitation by keeping the engine
constantly at work (even at low pow-
er) as was suggested by Esnault-
Pelterie (1912). However, this would
require prohibitive fuel consumption.
But there is an exceedingly simple
method of creating artificial gravity,
that of rotating the satellite. Accord-
ing to an idea advanced by Tsiolkov-
sky as far back as the end of last
century (1895), a spaceship (like that
shown in Fig. 25) should consist of
two connected sections. At the re-
quired instant these sections sepa-
rate, though remain connected by ca-
bles. Then, by using small rocket en-
gines they are given a rotating mo-
tion about their common centre of
gravity (Fig. 16). Obviously, after
the system has reached the necessary
angular velocity, rotation will con-
tinue in the vacuum of outer space
without the engines working.

Summing up, we see that physio-

logically there will be no insuperable barriers to the existence of humans on artificial satellites or spaceships. During powered flight the cosmonauts will undoubtedly be able to withstand for several minutes an acceleration of four gravities. This will make it possible to give the rocket a sufficient speed without expending too much fuel.

As to coasting flight in a rocket with engines off and on an artificial satellite, we are not fully convinced that lack of gravity will have no adverse effects on the human organism over extended periods of time. But even if it is harmful, this should not impede the building of inhabitable artificial satellites and spaceships insofar as it is technically feasible to create a sensation of weight by means of rotation.

The encouraging experience of the test animal in Sputnik No. 2 indicates that after the engines of the spaceship are switched off, the astronauts will apparently be able to create artificial gravity, and, at any rate, will be able to wait passively until automatic devices set the satellite (or spaceship) in rotation.

5. Problems of Eating and Breathing

Though the problems of supplying space travellers with oxygen, water, and food in the hermetically sealed cabin of a space craft are even now solvable, specialists will still have to put in a lot of work to give them precise solutions. And these problems are not secondary if we recall that an interplanetary mission may last several years. Likewise still far from a final solution are problems of air-conditioning and establishing a closed cycle of water on board the space vehicle.

Opinions differ greatly as to the breathing and food rations of space travellers: some say less than four kilograms, while others suggest even 10 kilograms per 24-hour day. The ration of dry food ranges between 0.5 and 1.2 kilograms. For absolutely dry (dehydrated) food products, the lower level seems to be closer to the truth. Slightly

over one kilogram of oxygen is required to oxidize these products (a thing to bear in mind is that the respiratory process is closely associated with the digestive process: the more we eat, the more oxygen we absorb). Since carbohydrates in conjunction with oxygen produce fewer calories than proteins and fats, the latter should predominate in a space diet.

However, in high-quality food products, carbohydrates together with oxygen may compete with fats as regards calorific power. This allows for a variety in the menu of astronauts even when the weight of the food is kept at a minimum. Take, for example, the favourite food of the Indians of North America—pemmican (a paste of dried meat, fat and berry juice). Due to its high caloricity and preservability, it will probably be highly valued on an artificial satellite.

The 24-hour ration of water for one person is estimated at two kilograms. A sensible proposal in this respect seems to be to carry the water and oxygen in the form of hydrogen peroxide. This will permit reducing the volume of the oxygen tanks, because the oxygen would be packed away, as it were, in the water. Besides, when hydrogen peroxide is decomposed into water and oxygen a certain amount of heat is evolved which may be used to warm the living quarters.

A power plant for establishing a closed water cycle may prove advantageous only for spaceships and for permanent satellites. Here the total amount of water on board will be constantly increasing due to the synthetic water continuously being produced in the organism during the oxidation of hydrogen—a component part of dry foods.

6. The Hazards of Space Flight

Meteor Hazard. Misgivings have often been voiced as to the risk of a space vehicle meeting large-size meteors. How great is this danger and what protection against it have we?

The Earth is under a constant bombardment by meteors. In the course of a year thousands of meteorites hit the surface of our planet. These iron or stony bodies are of all sizes and enter the Earth's atmosphere at anywhere between 10 and 70 km per second. In their passage through the air they heat up to incandescence by friction (due to air resistance) and at times shine as bright as the Sun.

A meteor hit on a spaceship might mean its destruction for the tiniest puncture in the hull would let the air out. However, as experiments show, where pressure falls rapidly a human being is capable of retaining his self-control approximately 15 seconds, which is sufficient time to switch on the oxygen apparatus of the spacesuit.

Even microscopic meteors may gradually destroy the skin of the ship. This hazard is very real for artificial satellites that are in orbit about the Earth long periods of time, for, as the ancient saying goes, "constant dropping wears the stone."

In an experiment conducted in the U.S.A. in 1953 at heights between 40 and 140 kilometres, 66 impacts were recorded in 144 seconds. There were 4.9 impacts per square metre per second. In other experiments, microscopes revealed dents (attributable to micrometeoritic impacts) in polished metal plates that had been flown to high altitudes.

Effective methods of protecting a spaceship from the meteor hazard have not yet been found. However, we know that the distribution of meteoroids in space and time is not uniform. Detailed studies have been made of the orbits of many meteor swarms. Astronauts will take these data into account when selecting the trajectory and time of flight. During a "meteor calm," they will be able to make a trip to the Moon and back with hardly any danger of encountering a sizable meteor. Such is the convincing evidence of the first artificial satellite, which covered a much greater distance without the slightest "meteor accident."

When the spaceship gets beyond the orbit of Mars, the astronauts will have to contend with possible collisions with asteroids, or minor planets. To date, astronomers have spotted and charted the routes of 1,600 such bodies, which revolve chiefly in the space between Mars and Jupiter.

The combined mass of the known asteroids is roughly equal to that of all the meteoric material of the Solar System (approximately one-thousandth of the Earth's mass). It is obvious that a collision even with the smallest of these bodies (one kilometre across) would be the end of a spaceship.

The ordinary skin of a spaceship will be sufficient protection against meteoric dust, while a double or multi-layer skin would afford protection against small meteors that may be encountered during the voyage.

As for the larger meteors, it is possible that radar, which would automatically alter the course of the ship, could be used to take evasive action. But it must be pointed out that spaceships with their colossal speeds no longer have the "manoeuvrability" of their terrestrial counterparts. While a pedestrian has no difficulty in passing around an obstacle, the driver of a racing automobile finds the job much harder, and to turn a rocket plane is far more complicated. Naturally, there will be hardly any possibility of rapidly diverting a spaceship from its course. There is still a lot of scientific thinking to be done in this field.

It may be that the problem of meteor protection can be solved by firing projectiles at them. Everything, of course, will be automatic, from locating the meteor by radar to aiming and firing the anti-meteor machine-guns. A meteor that is heading for the satellite or spaceship will collide with the bullet and blow up at a distance, and only a tiny "splash" may hit the vehicle. These particles, apparently, will not be any more dangerous than meteoric dust, a sufficient protection against which is afforded by the ship's skin.

It will be easier to protect an artificial satellite from meteors than a spaceship. Indeed, the upper layers of the atmosphere will be partially protective if the orbit of the satellite passes at a height above the Earth at which on the one hand the atmosphere is so tenuous that resistance to the satellite's motion is nearly non-existent, and on the other, the air is sufficiently dense to give protection against the "fastest" small meteors. This altitude is roughly 200 kilometres. Although the air density here is tens of millions of times less than at the Earth's surface, a large part of the small meteors do not penetrate to this level.

It may be that during meteoric showers when whole streams of meteors fall earthward, artificial satellites will have to drop into orbits in the denser layers of the atmosphere (but not below 100 kilometres) which will offer partial protection. To overcome air drag, it will be necessary to turn on a small rocket engine, and also take measures to protect the hull of the satellite from overheating.

Harmful Radiations. The atmosphere of this planet is known to be a reliable guard to life on Earth from the death-dealing solar radiations that are absorbed by oxygen in the upper atmosphere as it is transformed into ozone.

Ozone is located in the stratosphere at a variable height ranging from 16 to 50 kilometres. For this reason, even a very low-flying artificial satellite will have no protection from the Sun's ultraviolet rays. True, recent research by high-altitude rockets has established that the ultraviolet radiation of the Sun is appreciably less intensive than had been supposed on the basis of observations made from the Earth's surface. This is why it seems possible that the skin alone of a space vehicle will be a sufficient shield against these radiations. Alternatively, the space between the walls of the vehicle may be filled with a layer of oxygen, which, like the atmospheric oxygen, will convert into ozone, thus creating a barrier to the ultraviolet solar rays.

As regards the windows of artificial satellites or spaceships, it is a well-known fact that even ordinary glass absorbs ultraviolet rays to a great extent.

It may be noted in passing that small doses of these rays are necessary for normal functioning of the organism (hygienists believe that the windows of dwelling houses should have glass that passes ultraviolet rays).

The solar spectrum also contains harmful X-rays, but they present no problem on space vehicles since they are easily absorbed by nearly all building materials.

Extraterrestrial space is also traversed by cosmic rays (mostly stopped by the Earth's atmosphere) which consist principally of protons and alpha particles (hydrogen and helium nuclei). If account is taken of the fact that these particles are endowed with speeds close to the velocity of light and that each square metre of surface of an artificial satellite is bombarded every 10 minutes by a million (and, possibly, several millions) of such projectiles, one can grasp the grave danger that cosmic rays have in store for space voyages. But it is not only this so-called primary radiation that is dangerous to the human body. When the primary cosmic rays impinge on the skin of a spaceship (or spacesuit) there will form a so-called secondary radiation, just as occurs when primaries enter the Earth's atmosphere.

Very little is known about the effect that cosmic rays have on the human organism. Laboratory experiments in this field are still in embryo. In this respect, of considerable interest are the experiments carried out in the U.S.A. with small animals that were sent up in stratostats to a height of 30 kilometres for close to 30 hours. Due to primary cosmic rays, black mice were found to have grey spots appear on their skin covering areas much greater than had been predicted. In other experiments, even 24-hour exposures produced no ill effects. After such experiments, the test animals must be kept under careful observation for a long time.

To verify the action of cosmic rays on the human body, the Swiss scientist Eugster carried out the following experiment. A tiny piece of preserved human skin was exposed to cosmic rays in a rocket sent up several dozen kilometres. This piece of skin was later successfully grafted to a human being: it had not lost its viability. Similar experiments were later carried out in the U.S.A. on a still larger scale.

But how will cosmic rays affect people during long missions aboard artificial satellites or spaceships? This question still remains open.

One way to protect humans from primary and secondary cosmic rays might be to cover the satellites with an armour of lead. At heights exceeding 100 kilometres, 35 per cent of the cosmic rays are stopped by 2- to 4-cm layers of lead. But to ferry up to an artificial satellite even a much thinner armour would entail incredible difficulties.

On an atomic rocket, astronauts will encounter an extra hazard, that of radioactive radiations of the nuclear fuel. It is conceivable that some of the parts of the orbital rocket will become radioactive and will affect adversely the living beings for a long time after the engine has ceased to operate. This calls for developing special (very light-weight) protective barriers against these harmful radiations.

7. Preparing for a Flight into Space

The few minutes of powered ascent will be the most tense for the crew of a space rocket: attaining the requisite speed at a definite altitude and achieving precise orientation at this instant will, in large measure, determine the over-all successful launching of the satellite vehicle. On Earth, an auto driver, navigator, or pilot can always correct a deviation of the automobile, ship, or airplane from the charted route. But piloting a space rocket during take-off will be exceedingly difficult not only be-

cause of accelerations experienced by the pilot, but also because he will have to act instantaneously.

It is therefore quite natural that space travellers will have to have proper physical training. All the more so since their bodies will have to stand up to accelerations of several gravities, zero-gravity conditions, low barometric pressure of the microatmosphere on the spaceship, and extreme temperature variations. Piloting a spaceship, and other operations will require not only profound knowledge but also extreme agility and a thorough preliminary training. The biological factor—man, his health and tolerance—will play no small part in accomplishing a space mission.

In preparing for the flight on the active portion of the trajectory, the crew can train on a centrifuge, which may be rotated so that the centrifugal force increases just like the thrust force of a spaceship rocket engine in real conditions. However, it is absolutely impossible to train oneself in terrestrial conditions to withstand protracted weightlessness.

Long-time training of astronauts and also an all-round check-up of the various devices of space vehicles in laboratory conditions akin to actual flight conditions are absolutely essential to the setting up of orbital and interplanetary rockets and artificial satellite vehicles. Such training may be conducted in dummy ships. Thus, for example, in the opinion of Amico (U.S.A.) the dummy space vehicle will have scientific measuring, control, and other instruments and devices, as well as emergency equipment. All instruments will be in operation to give an accurate picture of the physical conditions of "flight." The cabin of the dummy will reproduce to minutiae that of the proposed space rocket (or artificial satellite). It will have established in it equivalent temperature, acceleration, lighting, radiations, etc. Automatic devices will regulate the make-believe velocities, the inclination of the apparatus with respect to the celestial sphere, pressure in the tanks and pipelines, fuel consumption, etc.

During its imaginary flight at limit speed, problems of navigation along the "trajectory" will be solved. The experimental unit should also include a system of radio-telecontrol.

In reproducing the active portion of the flight path (powered ascent), account must be taken of decreasing (with height) gravity and air density, variation of aerodynamic resistance, variation of mass of the rocket, due in part to successive jettisoning of auxiliary stages.

Any desired air pressure may be produced in a barometric chamber, the effect of a reaction force may be substituted by centrifugal force, etc., but to create a state of zero gravity in the laboratory is impossible. The dummy will undoubtedly be handicapped in other ways, inasmuch as it is difficult to create the equivalent of the various hazards that will threaten astronauts in flight, such as cosmic radiations, meteoric impacts, and the like. Yet these deficiencies can stultify the entire experiment.

Astronauts discharging their duties during "take-off" must be dressed in protective "anti-gravity" suits to check the feasibility of working under such conditions. The crew must not only be trained to pilot the space rocket under normal conditions, they must also be able to make use of life-saving devices with lightning rapidity in emergency.*

Tests will have to be made of the effectiveness of life-saving devices in the case of puncture by meteoric impact, extreme heating or cooling of the skin, failure of the oxygen plant, or of the control, communications, and electric systems, etc.

In flight, the automatic devices will be under constant control of the crew, so astronauts will have to learn to take instrument readings and react accordingly.

* Training in the use of such devices is extremely important; in aviation, for example, pilot training includes a programme of escape in all sorts of accidents that in reality may occur once in 20 years of service.

In turn, the actions of space travellers in the dummy will be controlled and recorded from without. This will enable analyses to be made of mistakes.

Under the guidance of instructor controllers, the crew will first learn the different operations (navigational, lifesaving, etc.) and only after a thorough training will the whole space vehicle (orbital rocket or satellite) be put to the final test. This time, the actions of the crew in the dummy cabin will be followed not by picked instructors but by a whole staff of specialists in different branches of knowledge.

A programme of this type is necessary not only to reach the ultimate goal—rational designs of space craft and the training of qualified specialists to handle them—it likewise makes for day-to-day progress in this field. It may be mentioned that the training of test pilots for jet planes usually lasts several years.

III. ARTIFICIAL SATELLITES AND THEIR OBSERVATION

1. Orbiting Artificial Satellites

Unlike aircraft, artificial satellites cannot fly over the Earth along just any route. For instance, there is not the least possibility of making a satellite fly along the tropics or, even less, follow the polar circles; it cannot be made to follow a broken line; it is also impossible to cut or extend considerably the time a satellite flies from one city to another, etc.

The only orbits for an artificial satellite are circular or elliptic. Besides, like a body thrown at an angle to the horizon, it can only move in a plane that passes through the centre of the Earth (Fig. 17), that is, in the plane of a large circle. This is one reason why a satellite vehicle cannot move along a parallel of latitude, with the exception of zero latitude—the equator. The plane of the orbit of an

artificial satellite will remain fixed with respect to the celestial sphere.

Sidereal Period of an Artificial Satellite. The altitude of an artificial satellite determines its speed and thus the duration of its period of revolution about the Earth.

If there were no air resistance, a satellite launched at the very surface of the Earth with a velocity of 7,912 metres per second would make one complete circuit with respect to the celestial sphere and return to its original position relative to the stars and the centre of the Earth in 1 hour 24 minutes 25 seconds. This is the so-called *sidereal* period of revolution.

As the height to which the satellite is launched increases, the orbit becomes longer and the force of the Earth's gravity weaker. Therefore, the centrifugal force and the velocity of the satellite may be less.

Fig. 17. An artificial satellite can only move in a plane that passes through the centre of the Earth

The orbital period of an artificial satellite increases with the latter's distance from the planet. At a distance of two Earth radii, the sidereal period is 7 hours 17 minutes, while at double and triple distances, the time becomes 15 hours 44 minutes and 26 hours 3 minutes, respectively.

The period of a satellite may be calculated as follows. Knowing the height of the satellite and the radius of the Earth, we determine the length of the circular orbit, that is, the distance covered by the satellite during one circuit; we then divide the result obtained by the circular velocity. For example, the orbit radius of a satellite flying at a height of 6,378 kilometres is 12,756 kilometres, while the length of this circle comes to 80,152 kilometres. Dividing this value by the circular velocity, equal to 5,595 metres per second, we obtain 14,327 seconds, or 3 hours 58 minutes 47 seconds.

The periods of the first six artificial satellites range from 96.17 to 134 minutes (see Table I).

At the beginning of their existence, the orbital periods of the first two Soviet artificial satellites were 96.2 minutes and 103.7 minutes, while the American satellite "Explorer" I had a period of 114.95 minutes.

The Period of Revolution of an Artificial Satellite Relative to an Observer. As was pointed out above, the sidereal period of a satellite in orbit near the very surface of the Earth comes to 1 hour 24 minutes 25 seconds. Such is the period of the satellite relative to the celestial sphere or relative to an observer on one of the Earth's poles. But imagine the satellite's orbit in the plane of the equator and picture the satellite rotating (like the Earth) from west to east. When the satellite makes a full circuit relative to the celestial sphere, an observer on the equator will turn with the Earth through a rather big angle relative to the celestial sphere and will thus be a good distance ahead of the satellite. Only in 5 minutes 16 seconds will the satellite catch up with the observer.

Thus, the period of a so-called zero artificial satellite relative to an observer would be 1 hour 29 minutes 41 seconds. This is the time it takes the satellite to return to its original position relative to the observer. In other words, the observer now sees the satellite in the sky in its former position relative to himself, for example, in the zenith.

If the satellite moved in the plane of the equator in a circular orbit from east to west, an observer on the equator would be moving towards it. A satellite moving from east to west at the very surface of the Earth would have a period, relative to an observer, 4 minutes 41 seconds less than the sidereal period, or 1 hour 19 minutes 44 seconds.

The First Artificial Satellites in Orbit.

The first Soviet satellite was launched into an orbit inclined 65 degrees to the plane of the equator. It had a maximum height (apogee) of 950 kilometres.

The satellite's orbit was a slightly elongated ellipse, the difference between the length of the major axis and the minor axis coming to less than a quarter of a per cent, which almost makes it a circle. However, the centre of this "circle" was slightly displaced relative to the centre of the Earth.

At first the satellite had a period of revolution of 96 minutes 12 seconds, which began to diminish (though very insignificantly) due to atmospheric resistance. During the first three weeks the period diminished 2.3 seconds every 24 hours and in 23 days reached 95 minutes 18 seconds. Thus, during this time the number of circuits made by the satellite per 24 hours had increased from 14.97 to 15.11.

The size of the orbit diminishes with the period. Calculations show that during the first 18 days the major axis diminished by roughly 70 kilometres (half a per cent).

The plane of the satellite's orbit slowly turned about the Earth's axis without changing the inclination with respect to the plane of the equator. This motion amounted to approximately one quarter of a degree of longitude per circuit of the satellite in a direction counter to that of the Earth's rotation.

Using official data, it is an easy matter to calculate that the average velocity of the satellite in the first three weeks of its existence was 7.58 km per second. But the orbital velocity of the satellite was not a constant value: it was slightly greater in the Northern Hemisphere where the approach to Earth was closest, and somewhat less in the Southern Hemisphere where the greatest height was reached.

The rocket that carried the satellite into its orbit first lagged behind the latter because the thrust with which the satellite was shot out of the carrier rocket somewhat retarded the rocket itself. Besides, the carrier rocket was retarded by the air to a greater extent than the satellite. Four days after launching, the carrier rocket was only one thousand kilometres behind the satellite. Later it caught

up to the satellite and even passed it. This occurred because the decreasing orbital velocity of the rocket resulted in a shorter orbit and the period of revolution of the carrier rocket became less than that of the satellite. Thus the angular velocity of the rocket over the celestial sphere began to exceed that of the satellite, and, therefore, to a terrestrial observer, the carrier rocket overtook the satellite.

Beginning from the time the carrier rocket passed the satellite (October 10, 1957), it began to pass to the east of the satellite, that is, it began to intersect a given parallel to the east of the satellite, and the angle of intersection grew from day to day. The result was that many asked whether these two bodies were not moving in different planes that were intersecting at increasingly greater angles. In reality, both orbits lay in the same plane. The carrier rocket passed to the east of the satellite due to the Earth's rotation and to the fact that it had overtaken the satellite. Thus, for example, on October 24, 1957, at 18 hours the rocket intersected a definite parallel of latitude and moved on, always in a fixed plane relative to the stars. The satellite following it arrived at this same parallel one hour later. But during this time the Earth turned on its axis $360°$: 24 (hours) $= 15°$. Consequently, the satellite intersected this parallel 15 degrees to the west of the point of intersection made by the carrier rocket. In other words, the carrier rocket passed 15 degrees of longitude to the east of the satellite despite the fact that both were revolving in the same plane.

Observational data of the carrier rocket of the first artificial Earth satellite showed that at the end of November 30, 1957, its period began to diminish noticeably and the rocket began to move earthward. This downward movement was especially rapid on December 1, 1957, along the route: Irkutsk, Chukotsk Peninsula, Alaska, and along the western coast of North America.

In its passage over this route, the carrier rocket of the first satellite entered the dense layers of the atmosphere,

and began to burn and disintegrate. Available data indicate that the remains of the carrier rocket fell on to the territory of Alaska and the western coast of North America.

All in all, the carrier rocket of the first satellite existed as an Earth satellite for about 58 days. Starting out with a period of 96.2 minutes and an apogee of the order of 900 kilometres, it covered, during this time, a distance close to 39,000,000 kilometres.

The first artificial Earth satellite existed as a cosmic body 92 days, during which time it circuited the Earth 1,400 times covering a distance of about 60,000,000 kilometres, which is as far as to Mars at the latter's closest approach to the Earth.

Observational data and trajectory calculations indicate that the first artificial satellite of the Earth entered the dense layers of the atmosphere on January 4 and ceased to exist, though its entry into the dense atmosphere and its incineration were not recorded.

Observations of the first artificial satellite made it possible to obtain valuable scientific information concerning the upper layers of the atmosphere and the laws of motion of artificial Earth satellites.

Sputnik No. 2 (the Second Soviet artificial satellite) was launched into a higher orbit than Sputnik No. 1, with its farthest distance approximately 1,700 kilometres from the surface of the Earth, which is some 700 kilometres higher than the apogee of the first satellite. The angle of inclination of the orbit to the plane of the equator was roughly that of the first satellite (65 degrees). The time of one full circuit was 1 hour 43.7 minutes. This is 7.5 minutes more than the initial period of Sputnik No. 1. During the first 70 days of the second satellite's existence, its orbital period showed a change of approximately 3.9 minutes. Whereas during the first few days the daily change in the period amounted to slightly over two seconds, by the thousandth circuit it had already reached about 4.5 seconds.

By applying the laws of celestial mechanics it was easy to calculate that the major axis of the orbit of the second satellite was about 700 kilometres longer than that of the first, while the perigee of the second one was at about the distance of the perigee of Sputnik No. 1 when it was launched. Inasmuch as the major axis of the satellite's orbit was 14,700 kilometres, and its period was 6,222 seconds, the mean orbital velocity of the satellite was 7.41 kilometres per second. On January 13 the second satellite completed its thousandth orbit, having covered during this time 2,200,000 kilometres more than the first satellite in the same number of circuits, or 45,400,000 kilometres, which is just over 3/4 the distance to Mars at its closest approach.

The second satellite stayed in its orbit in space longer than the first because it rose to heights where air resistance was practically non-existent. If the satellite orbited at a constant height of 1,700 kilometres, it would stay up for years. It was only near the perigee that Sputnik No. 2 experienced air drag, and even this was barely perceptible. But by the time Sputnik No. 2 had completed its thousandth circuit the maximum height of the orbit had dropped 370 kilometres, making the apogee 1,300 kilometres above the Earth's surface.

On the morning of April 14 the second Soviet satellite entered the dense layers of the atmosphere, broke up, and ceased to exist. During the five months and some that it was in orbit it completed nearly 2,370 circuits of the Earth, covering a distance of over 100,000,000 kilometres.

The third Soviet satellite was placed in orbit with an apogee of 1,880 kilometres and an initial period of 105.95 minutes. It made close to 14 circuits of the Earth every 24 hours. Preliminary estimates indicate that this satellite will be up for a longer time than the preceding two.

Initial apogee-perigee distances of the American satellites ranged from 3,968 kilometres (Vanguard I) to 187 kilometres (Explorer III) (see Table I, p. 25).

2. A Stationary Artificial Satellite

Due to the fact that celestial bodies mutually attract, it is impossible to build a satellite that will stay fixed in interplanetary space: such a satellite would be doomed to destruction. But it is possible to build a satellite which, though in movement with respect to the stars, will still be motionless to a terrestrial observer.

Indeed, as has already been stated above, the period of revolution of a satellite around the Earth increases with its distance from the Earth. While a satellite orbiting at a height of 265 kilometres requires one and a half hours to make one complete circuit, the Moon at a distance of 400,000 kilometres takes about four weeks. Obviously, there exists a distance at which the satellite will revolve in 24 hours.

If, in addition, such a satellite moves in the plane of the equator and also from west to east, its angular velocity will equal the angular velocity of the Earth's rotation and, thus, will appear to the terrestrial observer as fixed in space. It may be calculated that such a satellite (we shall call it a *stationary artificial satellite*) must be at a height of 35,800 kilometres above the equator. True, the Moon's attraction will produce certain perturbations in the satellite's orbit, and these, in time, will upset its "fixity," but such perturbations can be eliminated by properly correcting the trajectory.

To get a better picture of how such a "fixed" satellite could be set up, imagine a tower on the equator built to a height of 35,800 kilometres. As we ascend this tower the centrifugal force gradually increases (due to the increasing radius of rotation about the earth's axis) while the gravitational attraction to the Earth, on the contrary, diminishes. At the very summit both these forces balance. Now picture a gondola atop the tower. If the tower is taken down, then, as is evident from what has been said, the gondola will not fall. It will revolve about the Earth at the

same rate the latter rotates on its axis, remaining at a constant distance. To an observer on Earth, the gondola will appear fixed in space thus becoming a stationary artificial satellite.

A stationary artificial satellite would have advantages over other satellites. From it our planet would appear motionless, and the apparent diameter of the Earth would be roughly forty times that of the Moon as seen from the Earth, while the area of the visible disc would be 1,600 times greater. The crew of a stationary satellite would find it easy to make contact with the Earth via directional radio communication or light signals. A trip to the satellite could be made at any time without waiting for a proper alignment of the satellite and launching site.

Such countries as Indonesia, Brazil, Colombia, and others could build satellites that would "hang" in one place above the territory of the given country or would appear to "swing" above it (if the orbit plane was slightly inclined to the plane of the equator). But if it becomes necessary to build a satellite observatory to study the territory of some European country or of the whole of Europe such a satellite will have to pass over other countries and continents as well.

3. Observing Artificial Satellites

The visibility of an artificial satellite depends not only on its size, reflecting power, distance, etc., but also on its light contrast relative to the celestial background. Therefore, such a "star" may be seen only in the twilight of sunrise and sunset when the satellite is lighted by the Sun's rays while the observer on Earth is in the dark. Water vapour and dust suspended in the atmosphere impair appreciably the satellite's visibility. However, the chief difficulty is in its short period of visibility. The twilight period may exceed the period of the satellite relative to the observer; for this reason, there may be cases when the satellite

will be seen twice during the same twilight period, that is, first setting and then rising again.

To facilitate observation of an artificial satellite its surface might be covered with a phosphorescent substance. Alternatively, the satellite may be illuminated from within.

It may be pointed out that if the telemetry system on an artificial satellite fails, visual observations and radar will be the only ways to determine the movement of the vehicle.

Due to its great height, an artificial satellite may be tracked over a considerable part of the Earth's surface, and from it enormous expanses of the globe will be visible.

The first artificial satellites were easily distinguished from the other celestial bodies, because they moved across the sky to the North, North-East, East and South-East, and not to the West (or North-West, or South-West), due to the fact that they have not been launched against the Earth's rotation.

In time, with the coming of more powerful rockets, we shall be able to launch artificial satellites in the opposite direction so that this distinctive feature will no longer be present in them.

To conduct observations of artificial satellites at different points on the globe, it is not necessary to launch a large number of them in different directions. It is sufficient, for example, for a satellite to appear once over the North Pole and it will naturally have to fly over the South Pole too. The route of such a satellite will in future continue to be over the poles. Imagine an artificial satellite circuiting the globe 16 times every 24 hours at a height of 287 kilometres above the poles (265 kilometres over the equator). An observer on it would see the Earth as a disc covering most of the celestial sphere: visible would be the "cap," as it were, of our planet 3,700 kilometres across. This "cap" would be constantly in movement. As the satellite made

one revolution, the Earth would rotate 1/16th of its period and the "cap" would move at the equator a distance of 40,000:16=2,500 kilometres. Thus, the satellite would in 24 hours make 16 circuits enabling the crew to see the entire globe both in daytime and nighttime.

For a terrestrial observer, an artificial satellite orbiting at 200 kilometres from the Earth moves over the sky, at zenith, with the same angular (apparent) velocity as an airplane flying at an altitude of 7,130 metres at 1,000 km per hour, or one doing 500 km per hour at 3,065 metres altitude. It is clear, therefore, that there is no difficulty in keeping a moving artificial satellite in one's field of view. The apparent velocity of artificial satellites orbiting above 200 kilometres will be still less. As a rule, satellites will be placed only in very high orbits.

If a satellite vehicle is not in the zenith, but lower in the sky, closer to the horizon, its apparent speed over the celestial sphere is less and it is easier to follow. When it rises and sets, the satellite will be moving at its lowest speed relative to the observer. But as the satellite ascends, its angular velocity relative to the observer (the apparent velocity of the satellite on the celestial sphere) increases rapidly; it is the more rapid, the lower the satellite orbit (Fig. 18). If, by way of illustration, the height of an equatorial satellite is equal to the Earth's radius, its angular velocity relative to an observer at the zenith will be twice that at the horizon. But for an equatorial satellite orbiting at 300 kilometres height, the angular velocity observed at the zenith will be (relative to an observer) 22 times that at the horizon. After passing over the observer in the zenith, the satellite will begin to slow down (with respect to the observer) and when it sets its angular velocity will fall to that which it had when it rose.

The higher the satellite's orbit, the greater is the area on the Earth from which it is visible (Fig. 19). Thus, for example, a satellite circling at 200 kilometres will be seen from a territory with a radius of 1,500 kilometres, while at

an altitude of 1,000 kilometres the visibility radius will double.

The length of time an artificial satellite may be observed from a definite point on Earth will likewise increase with its height. Thus, for example, a satellite in orbit at 200 kil-

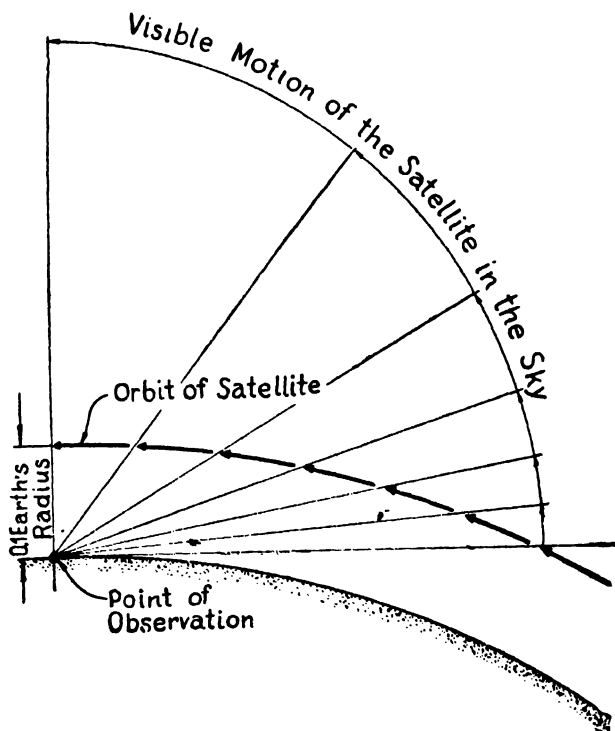Fig. 18. As the artificial satellite begins to rise it will appear to an observer to be moving slow-ly As it continues to rise its angular velocity rel-ative to the observer (the apparent speed of the satellite over the celestial sphere) will rapidly increase. When it passes through the observer's zenith it will begin to "slow down." At setting time its angular velocity will be the same as at rising time

Table II

**Localities over Which the First Soviet Artificial Satellite
Made Its First Appearance in October 1957**

Locality	Date	Hours	Minutes
Algiers	9	10	14
Alma-Ata	5	20	58
Ankara	10	22	37
Antarctica (coast)	7	06	—
Athens	12	22	36
Ashkhabad	8	21	02
Baku	12	21	00
Beirut	13	06	59
Belgrade	8	00	14
Berlin	13	00	16
Bombay	6	07	03
Brussels	10	08	34
Budapest	10	00	18
Bucharest	13	06	55
Buenos Aires	12	01	25
Warsaw	12	06	52
Washington	5	16	31
Vilnius	10	06	57
Damascus	6	08	34
Delhi	8	19	24
Djokjakarta	8	16	01
Dublin	13	08	29
Erevan	6	22	36
Kabul	6	20	58
Cairo	8	22	35
Calcutta	5	19	16

| Locality	Date	Hours	Minutes
Karachi	5	20	54
Kiev	7	00	15
Copenhagen	8	01	53
Leningrad	6	06	49
Lisbon	11	10	09
London	6	10	05
Madrid	9	10	12
Melbourne	8	12	38
Mexico	6	18	16
Minsk	10	00	19
Moscow	5	01	46
New York	7	06	36
Oslo	6	03	27
Ottawa	8	14	57
Paris	6	10	06
Peking	7	17	49
Prague	6	01	49
Pyongyang	11	16	10
Reykjavik	12	05	07
Riga	6	01	51
Rome	6	10	09
Rio de Janeiro	8	15	18
Istanbul	11	22	35
Tallinn	8	06	59
Tashkent	7	21	01
Teheran	8	07	01
Tirana	8	00	13
Tokyo	6	16	11
Ulan Bator	5	19	23
Frunze	6	21	01
Hanoi	7	17	43
Helsinki	8	01	56
Shanghai	10	16	10
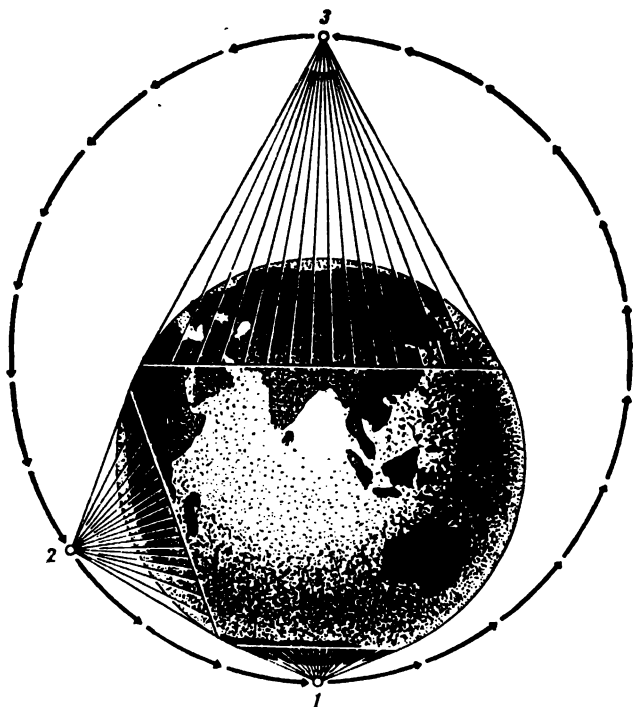
Fig. 19. How the diameter of the apparent circular segment of the Earth increases with the height of an orbiting satellite. At a height of 500 kilometres the diameter of the apparent circular segment is 4,900 kilometres (1); at 2,000 kilometres it is 9,000 kilometres (2); at 7,000 kilometres it increases to 13,700 kilometres (3)

ometres will be visible for 7 minutes, one at 500 kilometres will be visible for 11 minutes, while at a height of 2,000 kilometres, visibility will last 28.5 minutes.

Can an artificial satellite that has been detected, appear over some area all of a sudden? No, it cannot. It is sufficient to establish, at some instant, the coordinates of the satellite and its velocity and direction in order to be able to calculate at any future time its position and to predict

when and over what areas it will be flying. For instance, it is possible to determine whether the satellite will again appear over a given territory, and if so, when this will occur. It is, of course, assumed here that neither the direction nor the velocity of the satellite will be changed by firing a rocket.

One and the same satellite can pass over a given area first from south to north, then from north to south, but not because the satellite has suddenly changed its direction in the orbit (this is impossible), but because the direction of the satellite on the celestial sphere is reversed if, between two observations, the Earth makes half a rotation.

Observations of the First Artificial Satellites. Due to the fact that the orbits of the first Soviet artificial satellites were highly inclined to the plane of the equator, they passed over nearly all continents and bodies of water of the
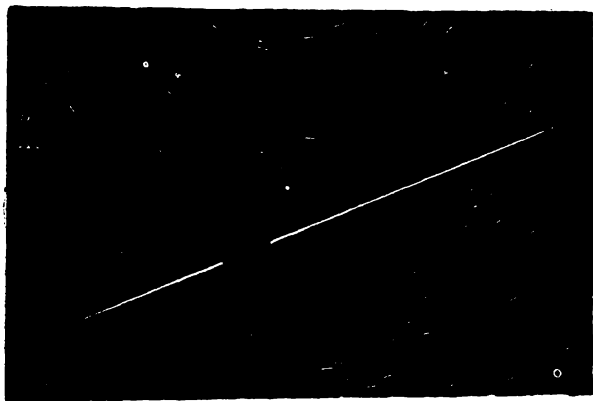

Fig. 20. The track of the carrier rocket of Sputnik No. 1 (this is a drawing made from a long-time exposure photograph taken by T. P. Kiselyova, Chief Astronomical Observatory, Academy of Sciences, U.S.S.R., at Pulkovo, October 10, 1957). One may gauge the relative speeds of the carrier rocket and the stars in their diurnal paths over the celestial sphere by comparing the lengths of the lines. The break in the track indicates the time and duration of the passage of the carrier rocket over the celestial sphere

planet (excluding the areas around the poles and narrow strips south of the Arctic Circle and north of the Antarctic Circle) to embrace nearly 90 per cent of the surface of the globe.

The first artificial satellite was spotted in all parts of the globe (Table II). It was observed with the unaided eye as a 5th-6th magnitude star, while the carrier rocket was of first magnitude.

Fig. 20 shows the track of the carrier rocket of the first satellite made by long exposure. It is easily seen how the carrier rocket streaks across the celestial sphere as compared to the stars slowly moving in their diurnal paths: the velocities are proportional to the lengths of the lines on the photograph (the astrograph used to take the picture was stationary). The figure also shows that the carrier rocket was moving at an angle to the direction of the daily motion of the stars. The break in the track of the rocket indicates the time and duration of its passage across the celestial sphere.

As has already been mentioned, the first artificial satellite had an elliptical orbit that was very close to a circle. However, due to the Earth's rotation the projection of the satellite on to the surface of the planet was a highly complex curve. Fig. 21 shows the satellite's projection on to the surface of the Earth during just over one period. After one full period, the satellite is in the zenith not over the same area, but over a different point of this same parallel approximately 24 degrees west of the first. (If this distance were exactly equal to 24 degrees, then 24 hours later it would be possible to observe the satellite at the same spot and in the same position; in reality, however, there are slight deviations.) Fig. 22 is a diagram of the movement of the satellite during 24 hours. As is seen, there are strips, between the areas over which the satellite passes, that never have the satellite in the zenith (here it may be viewed at a certain angle to the horizon). But given a long enough lifetime it may be in the zenith over these areas too. Even during the very first days of its existence the satellite exhibited certain
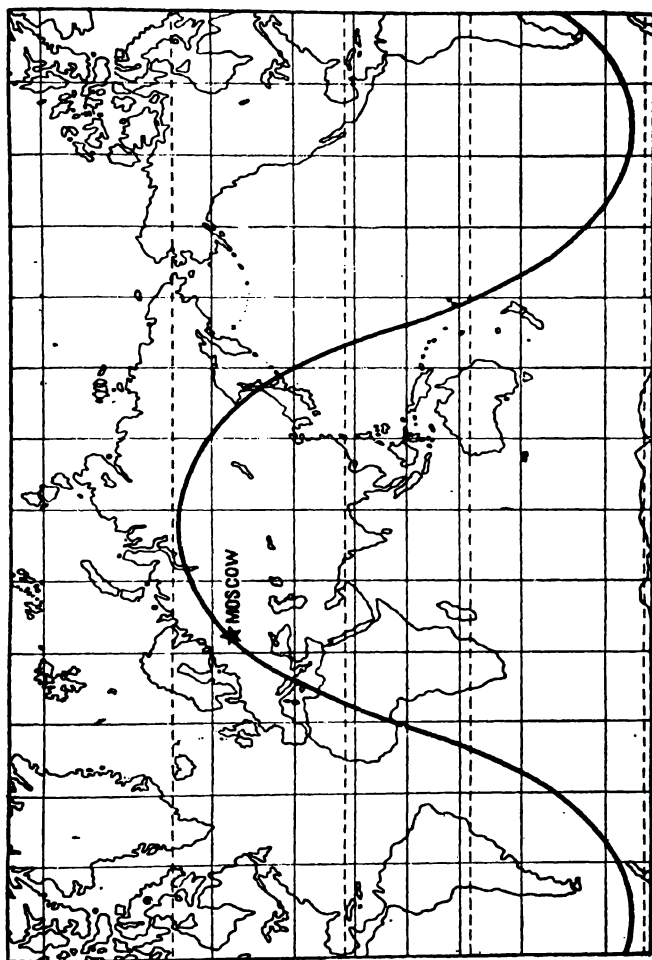
Fig. 21. The path of the first artificial satellite in just over one circuit round the Earth

displacements of the points of its projection as compared to the preceding 24 hours. By the end of October, 1957, Sputnik No. 1 had made so many circuits that the map of the globe would be a maze of the projections of its trajectory.

Immediately after the launching of the first artificial satellites, 66 visual-observation stations and 26 radio-observation stations in the Soviet Union went into action to track their movements. In addition, observations were conducted by means of radar, radio direction finders, and other instruments. Most extensive were, naturally, radio observations which were carried on by numerous amateurs at different points on the globe.

Two radio transmitters on the first and second satellites broadcast on 7.5 and 15 metres. This was very convenient for amateurs who ordinarily do not have sets capable of receiving on the shorter wavelengths. The satellites' transmitters emitted signals in the form of telegraph pulses lasting about 0.3 second with a pause of similar duration. Signals of the second frequency were transmitted during pauses in the signals of the first frequency.

Radio signals from the Sputniks were received at distances up to several thousand kilometres, and, in exceptional cases, up to 10-15 thousand kilometres.

After three weeks of continuous operation, the supply of electric power of the radio transmitters on Sputnik No. 1 was expended. Further observations of this satellite and of its carrier rocket, which was much brighter, were chiefly visual.

To detect the satellite, observers armed with optical instruments were divided into two groups: one group carried on observations along the meridian, the other, in the plane perpendicular to the apparent orbit of the Sputnik. In this way two "optical barriers" were established.

The ephemerides* of the satellites and of the carrier rocket were reported daily in the press, thus simplifying the work of observers: to locate the new heavenly bodies, astro-

* Ephemerides are the calculated positions of celestial bodies.
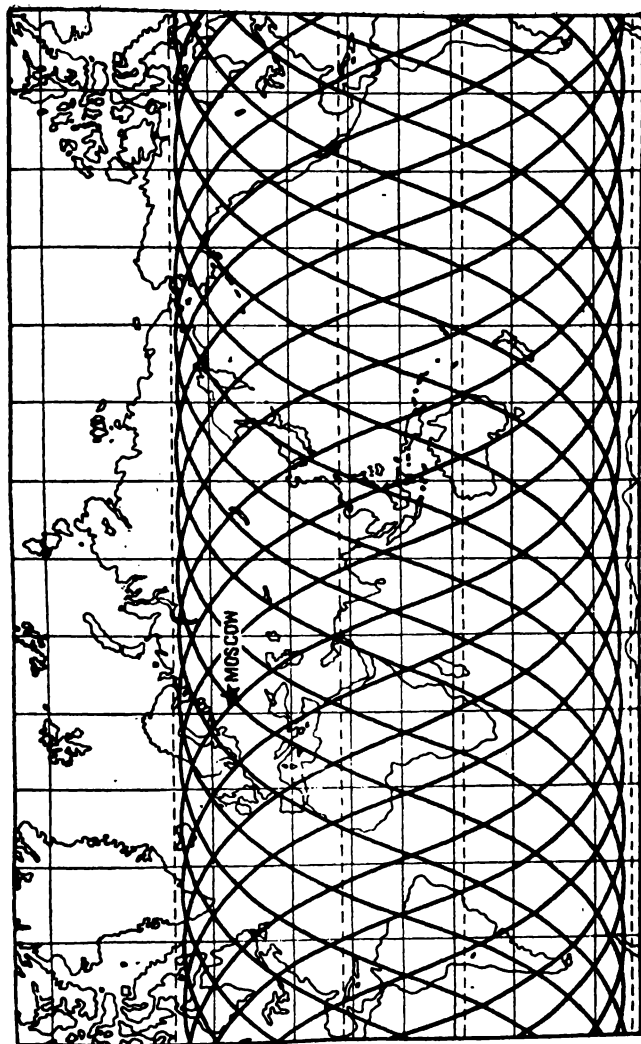
MOSCOW

Fig. 22. The 24-hour movements of the first artificial satellite

nomical instruments were directed at prescribed "waiting points." Errors of angular measurements made by visual-observation stations did not exceed one degree. Time was measured with an accuracy of one-hundredth of a second.

During one complete circuit of the satellite, observation stations on the Earth's surface moved (due to the Earth's rotation) anywhere between 1,100 and 2,600 kilometres depending on their location between the 65th parallel and the equator. But a satellite orbiting even at 200 kilometres is visible over an area with a diameter exceeding 3,000 kilometres. For this reason, in about an hour and a half after the satellite had set in the given locality it was often found again to be in the field of view of the observer.

Since Sputnik No. 2's orbit was higher than that of Sputnik No. 1, the radius of the area from which it could be observed was also larger. Whereas a satellite orbiting at 900 kilometres distance may theoretically be viewed from an area of radius 3,200 kilometres (over the arc of a large circle), for one at 1,700 kilometres distance this figure is 4,200 kilometres.

We have already noted that the inclination of the orbit of the second satellite to the plane of the equator was the same as that of the first satellite. And at a given instant the projections of the two orbits on to the earth ball were the same. This may lead one to think that the elements of motion of the two satellites were the same. But in reality they differed because their orbital periods differ and therefore the Earth, as it rotates on its axis, occupies different positions relative to the two satellites.

Sputnik No. 2 made 13.9 revolutions every 24 hours. Therefore, if we assume that the plane of the satellite's orbit remains fixed relative to the stars, after each revolution the satellite would pass over terrestrial latitudes displaced 25.9 degrees westward. But we know that the plane of the satellite's orbit is in slow rotation relative to the stars. For this reason, the distance between the points

of successive passages of the satellite over terrestrial latitudes works out to roughly 26.3 degrees.

Observational techniques and equipment connected with the third Soviet satellite have been radically improved. The satellite is equipped with several radio transmitters that permit measurements of its coordinates. These are carried out by a number of specially established scientific stations outfitted with all conceivable electronic devices.

Radar-measured data on the satellite's coordinates are automatically corrected to unified astronomical time and delivered to a general coordination-computation centre over special communication lines. Here the data arriving from different stations are automatically fed to high-speed electronic computing machines that digest all the material and derive the basic orbital elements. These are used to predict the satellite's future movements and to give its ephemerides.

This highly complex measuring system, which contains enormous numbers of electronic circuits and devices, computes the satellite's coordinates and orbital elements with a rapidity and accuracy that exceed by far those of the first two Soviet satellites.

In order to facilitate observations by scientists throughout the world, the satellite is equipped with a powerful radio transmitter that continuously radiates telegraph pulses of duration 150-300 milliseconds on a frequency of 20.005 megacycles per second.

4. The Movements of Celestial Bodies Viewed from Artificial Satellites

As soon as an orbital rocket is out beyond the perceptible atmosphere (this occurs one to two minutes after take-off), the celestial sphere loses its customary bluish colour and becomes black. On the Earth, areas shaded from the Sun do not experience absolute darkness because to one degree or another the sunlight is scattered there by the atmosphere. In contradistinction, cosmic regions shaded by a nonilluminat-

ing body are in nearly complete blackness. Here, the celestial sphere is not brightened up by sunlight scattered in an atmosphere; it shines by the faint light of stars and nebulae only. The stars do not twinkle and are always clearly visible if one cuts out the direct rays of the Sun. If this isn't done, the eye, adapted to the bright solar light, will lose its power to discern the stars.

From an artificial satellite the sky will appear quite different from what is seen from the Earth's surface. We in the Northern Hemisphere cannot see much of the southern celestial sphere, just as the greater part of the northern sphere is not visible to earth dwellers in the Southern Hemisphere. From an artificial satellite, regardless of the direction in which it is moving, it will be possible to review the entire celestial sphere in the course of one local ("satellite") day, that is to say, during one circuit about the Earth. During a local sidereal day, the Earth, to an observer on an artificial satellite, would appear to have made a complete revolution around the satellite.

If the orbit is circular, the motion of the Earth over the celestial sphere will be uniform. But if the orbit is elliptical, to an observer on the satellite the Earth will appear to first increase its velocity and then slow down again as it moves across the celestial sphere. This is due to the varying speed of the satellite itself and also to the varying distance from the Earth.

We have seen how the orbital motion of an artificial satellite about the Earth will affect the apparent motion of celestial bodies. Now imagine ourselves aboard an artificial satellite using rotation to produce artificial gravity. What will the motion of the celestial sphere appear like? First, the celestial sphere with the Earth, Moon, Sun, and stars will appear to be revolving about the satellite. It will make one complete revolution during the time that the artificial satellite rotates once on its own axis, which is several minutes or even a fraction of a minute.

If the axis of rotation of the satellite is horizontal, the

space travellers will see the Earth pass overhead and then under their feet. But if the satellite's axis of rotation coincides at a certain instant with the axis of rotation of our planet,* the Earth will appear to be rotating on its axis at a terrific speed (exceeding by hundreds of times the actual rate), and the Sun and stars will be revolving around the Earth at this same startling speed. Depending on the direction of rotation of the satellite, the Earth's rotation may appear to be either direct or retrograde.

If the axis of rotation of the artificial satellite (as we know, it must pass through its centre of mass) passes through the centre of the Earth, though does not coincide with the Earth's axis, the Earth will seem to be rotating not on its own axis, but about the axis of rotation of the satellite. To astronauts it will appear that the point on the Earth's surface from which the satellite is seen in the zenith is the Earth's pole. For this reason, to space travellers moving around the Earth, this imaginary terrestrial pole will appear to be wandering, but during one apparent rotation of the Earth on its "axis" the latter can move only a trifle.

As an extreme case, the apparent pole of rotation of the Earth may prove to be fixed. This will occur when the Earth is viewed from a stationary artificial satellite rotating on an axis that passes through the centre of mass of the satellite and the centre of the Earth. To take an example, the mountains of Kenya in equatorial Africa with their plantations of bananas and coffee trees may prove to be such a pole. In this case, to nonterrestrial observers the Kola Peninsula, which lies beyond the Arctic Circle, and Sumatra on the equator will be on one apparent parallel of latitude.

As we see, space travellers on an artificial satellite will have to spend quite some effort to master the art of cosmic

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* Since an artificial satellite cannot "stand still" over the pole, this coincidence lasts an instant.

navigation and utilize practical astronomy, say, to correct the vehicle's orbit.

We may remark that data on the motions of celestial bodies relative to automatic artificial satellites may also be useful in analyzing the results of instrument readings made on such flying observatories.

5. Days, Nights, and Seasons on Artificial Satellites

When, following the first automatic scouts of the Universe, human beings set out into space and become inhabitants of these new heavenly bodies—artificial Earth satellites—they will see much that is unusual. The celestial sphere will move differently, the seasons will change quite unexpectedly, and other phenomena will strike them as extraordinary.

On an artificial satellite day and night will follow each other as they do on Earth. But here they will differ from their terrestrial counterparts. Since in 24 hours an artificial satellite can make up to sixteen circuits about the Earth (this number varies with altitude), day and night on such a vehicle will change just as many times during the 24 earth hours. On the satellite, night is a sort of solar eclipse: the Earth shades the Sun. Since the Earth's shadow covers only a small portion of the orbit, night on the satellite is always shorter than day (Fig. 23). Thus, for example, the local day and night of an artificial satellite making 16 circuits in 24 sidereal hours will last 1 hour 29 minutes 45 seconds, while the longest "winter" night will amount to 37 minutes.

On an artificial satellite, just as on the Earth, night is preceded by dusk (Fig. 23). The satellite will likewise have a twilight period at dawn. But the evening dusk and the darkened dawn of a satellite body results from the passage of the satellite through the penumbra of the planet and not

(as on Earth) from light scattered by the upper layers of the atmosphere. The vehicle first enters the Earth's penumbra and later the complete darkness of the umbra. While the cross-section of the Earth's umbra gradually tapers off, and ultimately disappears, the cross-section of the penumbra becomes ever greater. During a local night on the satellite, the Sun will not be seen at all, but during twilight it will be partly visible.

We on Earth always delight in the magnificent scene of a setting or rising sun. The marvellous colours of sunrise and sunset are due to the passage of the Sun's rays through a thick layer of air. When viewing the rising and setting Sun on an artificial satellite the influence of the Earth's atmosphere will be still more enhanced by the double passage of solar rays through the terrestrial atmosphere before they reach the eye of the observer.

An artificial satellite will have its seasons of the year too, and they will manifest themselves in variations of length of day and night (as on the Earth), though the cause will not be the same as on our planet. Whereas on Earth, variations in length of day and night during the year are caused by the inclination of the Earth's axis to the ecliptic, on an artificial satellite they are the result of differing durations of the satellite in the Earth's shadow. "Winter" on the satellite coincides with the period of the longest nights, while "summer" is the period of the longest days.

The entire calendar of a satellite is determined by the fact that its circular path always lies in one and the same plane which is fixed relative to the stars. As an example, take an artificial satellite orbiting 210 kilometres above the poles. The plane of its orbit (and also the Earth's axis) will be inclined 66°33′ to the ecliptic. Let us assume that during the autumnal equinox this plane is parallel to the Sun's rays. The instant the satellite enters the Earth's shadow, night will begin. This will occur four minutes after the satellite has passed over the North Pole, and during these four min-

utes the satellite will be in the Sun's rays, though the region on Earth under it will be enveloped in darkness. When the Sun rises on the satellite, the surface of the Earth will still be in the shade, and this again will last four minutes until the satellite reaches the South Pole. Thus, day on the satellite will last $4 \times 4 = 16$ minutes longer than night and will have a total duration of 52 minutes. This will be the time of longest night on the satellite, and hence the season of winter.
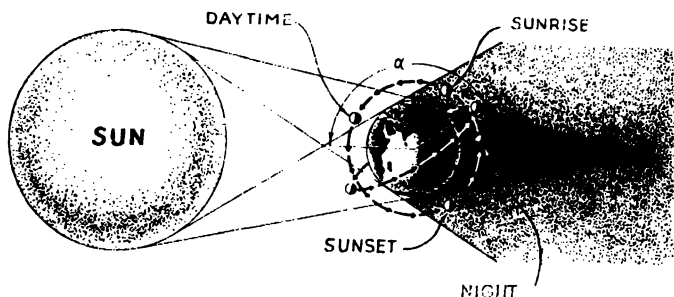

Fig. 23. Sunrise, daytime, sunset, and night on an artificial Earth satellite. α indicates the angle of inclination of the plane of the satellite orbit relative to the direction of the Sun's rays

On the satellite described above, June and December will be mid-summer, and the end of March and September, midwinter. Thus, during one Earth year, the satellite will have two winters and two summers.

A knowledge of the length of day and night and of the seasons of the year on artificial satellites is of great importance for observations from the Earth and for the study of solar radiation by means of instrumentation on the satellite.

IV. ARTIFICIAL SATELLITES PUT
TO USE

1. Flying Observatories and Laboratories

Unlike high-altitude rocket research with its limitations both in time (several minutes) and in space, satellites may be used for long-time investigations of unlimited space. In this way, an artificial satellite combines the advantages of balloons, which are capable of staying up above the Earth for long periods of time, and rockets, which are able to reach extreme heights.

First and foremost, artificial satellites will be useful as flying observatories to observe the Earth's surface. Such a satellite can be instrumented to keep automatic watch over the natural phenomena of the upper atmosphere and of the Universe. These automatic devices will record the results of their measurements and radio them back to Earth. Our knowledge of outer space will be enriched with numerous facts which at present we are unable to obtain from instruments flown on high-altitude rockets.

Precisely such a flying laboratory was the second Soviet artificial satellite—Sputnik No. 2.

Studying the Earth Ball. Using fifteen-power prismatic binoculars on an artificial satellite orbiting at 200 kilometres it will be possible to see terrestrial objects 4 metres in diameter. However, due to the rapid motion of the satellite the binoculars will have to be locked on to the object by means of a special mechanism. It will also be extremely difficult to distinguish detail on the Earth's surface on the horizon.

An artificial satellite will give man his first impression of the planet Earth hanging in space. But even today we know what the Earth looks like from the orbit of such a satellite. Fig. 24 is a high-altitude rocket photograph of a section of the Earth's surface. An infrared filter was used to pierce through what was nearly the entire atmosphere. The picture shows clearly defined details of the Earth's surface,

cloud aggregations, atmospheric layers on the horizon, and the Earth's curvature. An observer in the orbital observatory will see just about as much.

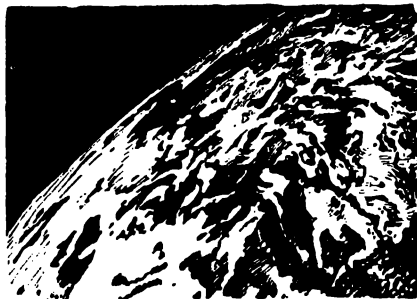At present, only 7 per cent of the Earth's land surface has been accurately mapped. Yet from an artificial satellite it will be possible, without any special effort, to map (by means of photographs) all inaccessible areas, to make old maps more precise and to account for changes produced by the construction of aerodromes, roads, dams, and the like. True, this would require recovering the film by having it automatically dropped back to Earth, and it is not yet clear how this problem can be solved.

Fig. 24. The surface of the Earth as seen from a height of 225 kilometres

The number of high-altitude photographs necessary to map the entire globe diminishes with increasing height of the satellite's orbit. From a satellite vehicle orbiting at a height of several thousand kilometres, the entire surface of the Earth can be photographed in daylight in less than 12 hours.

Admittedly, large areas will always be covered by clouds, but in such cases infrared rays and radar can be employed. But even in the total absence of clouds, with a clear sky, the air still remains very turbid. Nevertheless, pictures of the Earth's surface taken from an artificial satellite will be very precise, and distortions produced by the atmosphere when viewing through a telescope will practically be absent. For the same reason, it is easy to read a printed text through a piece of waxed paper held firmly to the text, while the letters blur out of all recognition if the paper is brought

close to the eye. It may be noted that the presence of cosmic and X-rays in extra-atmospheric space complicates greatly the photographic process from a satellite vehicle since conventional plate holders do not provide adequate protection for the photographic plates.

Television transmitters on artificial satellites of the Earth (or Moon) can transmit to observation stations simple or stereoscopic pictures of the terrestrial or lunar surface taken from orbital heights. To make stereoscopic pictures the two transmitting cameras will have to be located on two different satellites (one would be too small for the job) moving at approximately the same distance from each other. (It is also possible to obtain stereoscopic photographs of the Earth's surface from a single satellite by comparing pictures taken with one camera at different times.)

An artificial satellite could also be used to measure the Earth's radiation and albedo.* The latter varies over a very wide range due chiefly to the Earth's changing cloud cover. From a satellite vehicle there would be no difficulty in determining this value for different latitudes and seasons of the year.

Some authorities believe that precise observations of the motions of artificial satellites (even of minimal vehicles) will enable diverse measurements to be made, such as triangulation of the globe,** and especially of the expanses of water, measurements of intercontinental distances, etc. For instance, an artificial satellite could measure the width of the Atlantic Ocean to within 30 metres. Thus it will be possible, using artificial satellites, to confirm or reject once and for all the hypothesis of the relative movements of the continents.

It is known that depressions on ocean surfaces (a falling of the true level of the water as compared with the theoret-

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* Albedo is a number which shows what portion of sunlight is reflected by the planet (or satellite).

** Triangulation is a method of measuring the surface of the Earth by means of building networks of triangles.

ical level) reach as much as several hundred metres. There are also grounds for believing that the shape of the Earth is constantly undergoing change. All these alterations will be visible in the satellite observatories.

Although aircraft flying in the polar regions keep under constant surveillance the movement of ice in Arctic waters, and in forest areas are on the watch-out for fires, such observations made from satellites would be far more effective. Instruments on the satellite vehicles will warn ships at sea of ice packs. All sizable icebergs will be "on register" and will never again send ships to the bottom of the sea in collisions. Orbital observatories will report to Earth about forest fires in the depths of the taiga and will indicate the exact seat of the fire.

It may be that artificial satellites will also be used in emergency life-saving, to demine areas at sea, or to predict the movements of schools of fish. Satellites may be useful in determining the locations of sunken ships and aircraft, and perhaps even of lost expeditions.

Opinions have been expressed that in future artificial satellites may be used to conduct oceanographic, glaciological, and seismologic studies. Glaciologists, for instance, hope that observations made from artificial satellites will confirm the hypothesis of the gradual tendency towards moderation of the climate and attendant slow melting of the ice cover of the planet.

Studies of the Atmosphere. Artificial satellites will be employed in meteorological observations. They will keep track of the areas and movements of clouds, they will determine the character of the cloud undercast, the boundaries of warm and cold air masses and the movements of storms. Even on land, which occupies less than 30 per cent of the Earth's surface, there are too few meteorological stations: tens of thousands of these stations are incapable of giving a complete picture of the cloud cover of the Earth not only over the immense water expanses of the globe, but even over the continents. Specialists are of the opinion that there

will still be many difficulties in the way of determining the movement of large cloud masses from an orbiting satellite since the outlines of the continents themselves will be lost under the cloud cover. Hence, the difficulties of determining how much the clouds moved and how their proportions altered during one satellite circuit.

The density of the upper atmosphere may be determined indirectly, by means of artificial satellites that are even uninstrumented. Visual or radar observations of the satellite movements and the degree of retardation by air drag will suffice.

The satellite can eject at regular intervals sodium vapours which luminesce brightly in the Sun's rays. The temperature of the upper layers of the atmosphere can be evaluated from the dispersion of the sodium trace, and any distortions in the sodium "cloud" will serve as aids in determining wind velocities at a given altitude.

Just as properly equipped meteorological stations enable measurements to be made of different meteorological elements at a distance (remote-controlled meteorological stations), so with the aid of artificial satellites it will be possible to determine the temperature, pressure, and air density at various altitudes. A polar satellite, for instance, permits of rapidly determining parameters that characterize the state of the atmosphere and other data at a constant high altitude along a meridian.

The first Soviet artificial satellite—Sputnik No. 1—radioed to Earth its temperature and other data by varying the durations of the signals and pauses between them, which averaged three-tenths of a second.

The foregoing shows how important artificial satellites will be in producing correct weather forecasts.

It has been established that at high altitudes the atmosphere of the Earth glows. Even at 120 kilometres altitude in the daytime the celestial sphere is not black. At this height, air-glow is four per cent of the corresponding value at sea-level in the zenith, and does not disappear at night either.

On a satellite orbiting the Earth, it will be possible to investigate variations in the radiation proper of the terrestrial atmosphere as a function of time of year and geographical coordinates.

Studies of the Ionosphere and the Propagation of Radio Waves. Artificial satellites may be used to study ionization of the atmosphere (the area occupied by ions and electrons at different altitudes) which should be very helpful in forecasting conditions of radio communication, to name but one field of application.

In view of the fact that the distance between the satellite and the receiving station on Earth will be constantly changing and the air layer between them increasing and decreasing, the quantity of ions between the transmitter and receiver will also vary. Correspondingly, there will be variations in the nature of the radio signals received from the satellite due to the different positions it occupies relative to the receiving station, and this is what will permit an assessment of the state of the ionosphere.

Relatively short-range radio stations on ships will be able to maintain contact with the homeland via the satellite, which can appear daily over the horizon. Such contact can also be established by using light signals, which find it much easier to pierce the atmosphere upwards since in this way they shorten their paths in the absorbing medium.

Artificial satellites can also serve to relay ultra-short waves, for example, television broadcasts, over long distances. True, due to the complexity of the apparatus and the huge power sources required, this use is not yet envisaged, but there is a chance that in the future, satellites will be worth using to broadcast television programmes from one continent to another.

Ionosphere studies occupy a central position in the research programme of the third Soviet artificial Earth satellite.

Studying the Earth's Magnetic Field. The magnetic field of this planet has been rather thoroughly studied at the

surface, and the results of these investigations have long been applied in naval and air navigation, in geodesy, and in other fields. The Earth's magnetic field is composed of a constant field created by sources within the Earth, and a variable field that arises from electric currents circulating in the ionosphere and extra-atmospheric space. The periodic smooth variations of the Earth's magnetic field are diurnal, 27-day (these are related to solar rotation), annual, 11-year (related to the period of solar activity), and secular. Sharp variations in the Earth's magnetic field (magnetic storms) are also observed. It is believed that this field produces a deviating effect on charged particles moving about the Earth. Alternatively, there is an opinion that it is due to charged particles from the Sun entering the atmosphere that we observe variations in the terrestrial field.

Through the employment of artificial satellites, especially those orbiting elliptically, it will be possible to make a magnetic map of the area about the Earth and to study the causes of magnetic anomalies, which are deviations of the intensity of the Earth's field from the mean ("normal") values of a given locality. It will be possible to investigate the influence of electric currents, arising at very great heights, on the Earth's magnetic field, to study the effect of variations in the intensity of cosmic rays on the course of magnetic storms, and also attack other problems. Investigations of the magnetic field of the Earth through the use of artificial satellites will be valuable both scientifically and practically. For instance, such studies will make it possible to detect mineral deposits and to determine their reserves.

Biological Studies. An artificial satellite will help solve problems of prospective interplanetary travel. Here it will be possible to study the effect of weightlessness on physiological and psychical processes, and also the action of cosmic, solar, and other radiations on living beings unprotected by the Earth's atmosphere. An artificial satellite can be used to verify Tsiolkovsky's idea that in zero-gravity con-

ditions plants and animals of all types, from the simplest to the most complex, will grow and develop much faster than under gravity conditions.

Meteors, Micrometeorites, and "Cosmic Dust." It is believed that micrometeorites affect in some way the state of the ionosphere and thus the propagation of radio waves.

Micrometeorite counters will be installed in satellites and it will be possible to determine the distribution of these particles, their momenta and electric charge as a function of the geographical latitude. The acoustical effects of micrometeoritic impacts on the skin of the satellite may be recorded by a crystal microphone in the satellite and telemetered to Earth after amplification of the radio signal.

The third Soviet satellite is equipped with special devices that record micrometeorite impacts.

Due to micrometeorite hits on the polished hull of the satellite, the latter will begin gradually to lose its lustre. This phenomenon too may prove a considerable aid in studying the peculiarities of micrometeorites. Another method is to coat the skin of the satellite with a radioactive substance and by tele-measurements of the satellite's radioactivity, as the intensity gradually diminishes, one can estimate how much of the material has been worn away by meteoric dust and micrometeorites.

An artificial satellite can be hermetically sealed and filled with a gas under pressure before launching. This will give it the rigidity it will need to withstand the high launching accelerations. And when in free orbit, any reduction in gas pressure will imply that a meteor has punctured the skin of the satellite. The length of time the satellite exists without mishap will be an indication of the possible frequency of meteor hits, while the rate at which the pressure falls will indirectly give the size of the meteor and its velocity.

From an artificial satellite, meteors entering the Earth's atmosphere will be seen not on a star background, but on the background of the Earth in the darkness of night. It may be that these new conditions of observing meteors will

extend the possibility of their study. On a satellite it will be possible to collect samples of meteoric dust and determine its influence on the weather.

In interplanetary space there is also found what is known as "cosmic dust." At times it has been found even on the Earth's surface. Artificial satellites can be used to make a study of cosmic dust too. Particles of interplanetary dust will not (practically speaking) impede the movement of a satellite vehicle.

Artificial Meteors. Artificial meteors of definite shape and composition may be thrown from the satellite. This should provide a wealth of material in the study both of natural meteors and the conditions of atmospheric braking of spaceships. It would be sufficient to launch, from an artificial satellite orbiting at from 200 to 1,000 kilometres, a meteoric body at a speed of 50 to 250 metres per second (in a direction opposite to that of the satellite) for it to enter the atmosphere at 8 kilometres per second. And—this is very important—in each case not only the speed of entry into the atmosphere will be known, but also the meteor's path from launching to entry into the air. Terrestrial observatories will be posted on all these data and on the time of launching of the meteors. Attempts have already been made to register photographically the paths of such artificial meteors (metal balls) thrown out of high-altitude rockets.

Astronomical Observations. Out beyond the atmosphere it is easier to study the aurorae and zodiacal light* insofar as glow in the upper layers of the atmosphere distorts the normal picture of these phenomena. It will become possible to study in detail the so-called "gaseous tail of the Earth"—a long extension of the very top layers of the atmosphere on the side of the Earth roughly opposite to that of the Sun.

* Zodiacal light is observed as a faintly illuminated cone on the background of the night sky at a definite time of the year before sunrise or sunset in the region of the zodiacal constellations, that is, along the ecliptic.

Even at night the atmosphere is a handicap in photographing very faint celestial objects by means of astrographs, while in the daytime the air mantle of the Earth makes observation of the stellar sky absolutely impossible. But at the height of an artificial satellite the atmosphere will no longer cause distortions, thus producing ideal conditions for astronomical observations. Stars that do not twinkle are much easier to observe and photograph. In such conditions one can take pictures of the planets and their satellites with any degree of magnification, while in terrestrial observatories even a thousandfold magnification is complicated by atmosphere-produced optical turbulence. Besides, on an artificial satellite astronomical optical observations will not depend on the caprices of nature.

The possibilities of radio astronomy will also be extended since many of the radio waves from outer space that do not reach the Earth's surface can be caught before they enter the atmosphere.

In the future, artificial satellites will have electronic instrumentation with television transmitters so that observers on the Earth will be able to view the sky by proxy through telescopes on the satellite.

An artificial satellite can also be useful in the study of cosmic rays outside the atmosphere, one of the problems being to determine the abundances of the nuclei of lithium, beryllium, boron, and other elements. Of great importance too are investigations of the variations of cosmic ray intensity (and ionization produced by this radiation) as a function of time, height, and geographic coordinates.

Selecting the Proper Orbits. We see that artificial satellites will find diverse applications. But different phenomena will probably call for satellites moving in specifically selected orbits. It is clear, for example, that equatorial satellites are not suited to the study of the aurorae, while polar satellites will offer nothing in the study of the zodiacal light.

Special applications will be found for varying-altitude vehicles which will move in elliptic orbits through the more

tenuous upper strata of the ionosphere and the denser air closer to Earth. This will permit observations to be conducted at various altitudes and make it possible to fill in the gaps in our knowledge concerning solar radiation, the composition of the atmosphere at different heights, the distribution of ozone, the Earth's magnetic field and ionospheric storms, etc.

The Southern Hemisphere has little land but has broad expanses of water, and so it should be of interest to have a satellite orbiting above the Northern Hemisphere longer than over the Southern Hemisphere. This may be done by lengthening the northern part of the orbit and accordingly reducing the velocity of the vehicle on this portion. In other words, the satellite should be placed in an elliptic orbit with its perigee over the South Pole. The higher the apogee of the orbit, the less time the vehicle will spend over the Southern Hemisphere and the more time over the Northern Hemisphere.

The Future. The study of many of the problems touched on above has only begun and will require many years of investigation. So in the immediate future, artificial satellites will be employed in the study of a rather narrow range of questions.

Undoubtedly, in time, artificial satellites will uncover phenomena whose existence at present is hardly even suspected.

2. Artificial Satellites as Interplanetary Stations

Astronautically speaking, the best use of artificial satellites is in the form of space stations.

To get to the Moon, Venus, or Mars—our closest celestial neighbours—a spaceship will have to develop a take-off speed some thirty odd times the velocity of sound. The building of such a ship is beyond the reach of present-day technology. To simplify the solution of this problem one can divide the cosmic journey into stages by using an artificial Earth satellite as a sort of transfer station, as was suggested in the nineties of last century by Tsiolkovsky.

On the Earth, stops at stations, ports or airdromes permit trains, ships, and airplanes to take on supplies of coal, water or petrol, while passengers replenish their stocks of provisions. And sometimes a fresh locomotive is hitched on or a new plane is brought out to continue the journey. Very similar will be the designation of an interplanetary station in space travel. Such a station could serve as a spring-board for man's next jump into the outer realms of space. Here space travellers could put up everything necessary for continuing and completing their cosmic mission: fuel, which the rocket could not have carried if fired from the Earth's surface, equipment, provisions, etc.

The spaceship and payload required for the voyage can be first ferried up to such a station piecemeal. This will lighten the ship since take-off from a satellite platform requires much less fuel than from the Earth directly.

Unlike people travelling about the Earth with stops at intermediate stations, space travellers taking off from an interplanetary station put away, as it were, both the distance covered and the acquired speed.

In some versions of spaceship design, the interplanetary station can also be used for the return journey: the crew would transfer to a space glider to make the descent to Earth.

As a rule, satellites orbiting over the poles, though convenient for purposes of observation, are not suitable as space stations, and the reason is this. It is necessary that the station should move together with the Earth in the plane in which our planet moves around the Sun (the so-called plane of the ecliptic; all the other planets of the Solar System move in approximately the same plane). Only in such a case will the direction of motion of a spaceship taking off from an interplanetary station be more or less parallel to the motion of the Earth and its orbit, which is an extremely important fact for missions into outer space since the orbital velocity of the Earth will be added to the take-off velocity of the ship helping it to overcome the attraction of the Earth and Sun.

For space flight, the chief merit of the intermediate space station is the fact that it is in motion. When a rocket stops at the station it retains its velocity and uses it again for the next lap. Thus, for example, calculations show that a rocket leaving an artificial Earth satellite for the Moon, Venus, or Mars has to develop a speed of only 3.1 to 3.6 km per second in place of the 11.1-11.6 km per sec. when taking off from the Earth's surface, because the station itself already has a velocity of 8 km per sec. This means that a rocket capable of rising 1,000 km from the surface of the Earth (and such flights have been made) could reach Venus or Mars if it started from a space station.

Most of the projects of interplanetary travel provide for the astronauts making transfers (at space stations) to ships assembled in the shops of the station from parts ferried up from the Earth. The interplanetary ship will use the engines and other parts taken off rockets arriving at the station from the Earth. The flight conditions from Earth to an artificial satellite differ radically from those between the satellite and the point of destination. For this reason, the rockets for these flights should also differ in design.

A spaceship for shuttling between the Earth and the artificial satellite will have to be streamlined since it travels through the entire atmosphere. It will have a powerful engine capable of developing a velocity of close to 8 km per sec., and, hence, a large fuel supply. A ship taking off from the satellite into deep space does not necessarily need to be streamlined because it will not encounter the resistance of any material medium. The fuel tanks can then be made spherical which will reduce their weight for a given volume.

Rockets will not have to be so powerful for take-off from an artificial satellite as for starts from the Earth's surface. Indeed the thrust needed at the Earth's surface must be more than the weight of the rocket, while in taking off from a satellite vehicle this is not essential. A rocket, even with the thrust far less than its weight on the Earth, will be able gradually to build up the required speed. In an Earth

take-off the bulk of the engine power is consumed usefully, yet a large part is lost (for instance, in air drag), and if the engines stop, the rocket will fall back to the Earth. Now a ship leaving a space station does not face this danger: even if the rocket engine ceases to function, the ship will not fall back either to the departure station or to the Earth. The spaceship will therefore require far less fuel than in a terrestrial take-off, hence another factor in favour of the use of an artificial satellite as an interplanetary station.

According to some designs, a rocket arriving at the station from Earth will continue to serve on the subsequent deep-space mission, but first it will shed its streamline fairings. And it will no longer have any need for its stabilizing fins and vanes. If a change of course is wanted in space the rocket ejects a jet of gas in the proper direction. After refuelling at the space station the rocket will continue on its mission. Naturally, the more fuel a rocket leaving an interplanetary station takes on board the higher will its ultimate velocity be. But this is not always so in a take-off from Earth. Unlike a satellite take-off, where additional fuel always produces a positive result, a terrestrial take-off may (due to an excessive load) give a negative result (less speed and altitude).

However, an artificial satellite is not a necessary lap on lunar and planetary missions, which may be made without stopping over at an interplanetary station. But the take-off in this case will be slightly different. The rocket will take off from the Earth, develop a speed of 8 km per sec. and become an artificial satellite at an altitude of 20C-300 km. Auxiliary rockets will then ferry up to this rocket satellite additional cargo and fuel necessary for the next lap. Replenished with supplies, the interplanetary rocket will start out on its mission. This solution is of interest from the standpoint of reducing the meteor hazard which a temporary artificial satellite would be subject to for only a brief period of time.

Long before man sets out into the boundless realms of the Universe, the conditions of such voyages will have been tested on an interplanetary station. It will be possible to determine whether protracted zero-gravity conditions affect the human body adversely, to find out the effect of artificial gravity, etc. This celestial island will afford opportunities to study means of protection against the meteor hazard. Using the space station as a base, astronauts will be able to go through a complex course of navigation in airless space not far from the Earth and also master the art of braking in a gliding descent home.

An interplanetary station could also be used to get data necessary for creating rationally designed spaceships and gliders.

It may be remarked that the employment of an artificial satellite as an interplanetary station or—and this is basically the same—the conversion of a spaceship into a temporary Earth satellite will apparently be the rule only during the first stage in the development of space-flight techniques. The powerful atomic ship of the future will not need to go into a circular orbit and receive "supplies" from Earth when it takes off for the Moon or planets. Also, it may be that the sending of small composite guided rockets to the Moon and planets will be simple to accomplish in a take-off directly from the Earth's surface.

3. The Problem of Natural Interplanetary Stations

In astronautical literature one can come across suggestions of utilizing the Moon as an interplanetary station. But the Moon is too far from the Earth's surface to be of any use in this way. Besides, since its mass and, consequently, its gravitational pull are relatively large, no small amount of fuel would have to be spent first on retardation in landing and then again on the take-off. As an example, let us take an expedition to Mars. Calculations show that if an artificial satellite close to the Earth is used as transfer station,

a spaceship making the jump from Earth to station and from station to Mars will have to develop a lower total velocity (and, hence, will expend less fuel) than for a single trip to the Moon. The reason is that in landing on Mars the ship can be slowed down by utilizing the resistance of the gaseous envelope of the planet, while a landing on the Moon would require the expenditure of rocket power since there is no atmosphere to speak of.

To use the Moon as an interplanetary station would be impracticable unless very high-quality fuel and materials of construction were found there.

To sum up, an artificial satellite has a number of advantages over the Moon as an intermediate space station. First, it may be placed sufficiently close to the Earth, which means that ferrying will be faster and require less fuel. Second, the practical absence of a field of gravitation of the satellite would allow for economy in fuel to the extent that the latter would be used in landing on the Moon and subsequently taking off again.

But hasn't the Earth a second moon or even several natural satellites which are closer to the Earth than the Moon we know, but which have not yet been detected? The other planets have several satellites apiece! Take Jupiter with its 12 moons and Saturn with nine satellites. Some of the satellites of other planets are extremely small: Phobos and Deimos of Mars are 14 and 8 km across, respectively. Even if a second natural satellite of the Earth were exceedingly small it would be a fine base for deep-space exploration. The discovery of such a satellite (or several such satellites) would in large measure simplify the solution of lunar and planetary voyages, obviating the necessity of building an artificial satellite. On a natural satellite it would be relatively easy to equip both a flying observatory and an interplanetary station.

Quite naturally, if such satellites do exist they can only be veritable midgets and to detect them will be a task of immense complexity. Owing to its tremendous speed, such

a dwarf satellite could not be caught in a telescope, all the more so if it is orbiting close to the Earth. And what is more, if it is very close to the Earth it may not leave tracks in a photographic plate due to the insignificant time of exposure. Besides, when such a satellite enters the Earth's shadow it does not shine, thus making observations of it possible only during a very brief period of time. Astronomers allow for the possibility that such a satellite has been observed but it could have been taken for a meteor. Radio astronomy techniques, which have developed during recent years and are being applied to meteor studies, may be useful in solving this problem. Observations in this direction are now being conducted, for example, by the Meteor Institute in New Mexico (U.S.A.) under the leadership of C. Tombaugh who in 1930 discovered the planet Pluto.

Obviously, if new moons are discovered they will be found outside the atmosphere. Otherwise they would have long ago fallen to Earth or been burnt up by atmospheric friction.

The natural interplanetary stations of other bodies of the Solar System are likewise of great interest to astronautics. Thus, for example, reconnaissance flights around Mars will obviously precede a landing mission (this probably applies to lunar flights too). For this mission, the rocket ships would temporarily become artificial satellites of Mars. Indeed, to land on a planet and then take off again would in the initial stages of space flight entail tremendous difficulties, and especially since all the fuel required for the return trip would have to be brought from the Earth.

V. ON BOARD THE SPACESHIP

1. Take-off

An automobile, train or sailing boat moves as long as a force is applied: as long as the engine runs or the wind bulges the sails. But turn off the engine, furl the sails or stop heating the boiler of the locomotive and the motion ceases.

True, these vehicles do not stop immediately after application of the moving force has ceased, they coast along a certain distance. But the distance is short because the accumulated energy is rapidly absorbed by friction and air resistance.

A spaceship is something quite different. In a few minutes its engine develops a high speed, after which the rocket ship moves under its own momentum in interplanetary space where it encounters neither friction nor air drag.

The faster a space rocket attains the requisite velocity the less time the engine has to work against gravity and the less fuel is required.

A tremendous saving in fuel can be achieved if the ship is accelerated instantly to the needed speed and then continues the flight under its own momentum with the engine off. However, this is impossible practically, for a rocket naturally gains speed only gradually, as the fuel burns. Besides, the speed of take-off is limited by the endurance of the human body.

Books on interplanetary travel frequently exhibit on their covers rockets moving moonward from the Earth along a straight line. Such a rocket has already covered half the distance or is even close to its destination and the engine is still working. Such a picture is not at all correct. In reality the flight path of a spaceship is not a straight line and its engine will be turned off a few minutes after take-off, in the vicinity of the Earth. Only in this way can the ship save enough fuel for the return journey.

The fate of the whole voyage depends on a properly selected take-off trajectory. Trajectories involving minimum fuel consumption are very complex. The rocket has constantly to alter its direction and acceleration. If a simplified flight path is taken (vertical, for instance) fuel consumption will increase severalfold.

Likewise decisive for the entire journey is the precisely selected time of take-off since both the Earth and the point of destination are in motion.

2. In Flight

The engine has just been switched off. Now over a portion of the route (exceeding 99 per cent of the entire distance) the spaceship will move under its own momentum. For example, in journeys to the closest heavenly bodies the rocket engine will be in operation some 2,000 kilometres, while the distance to the Moon is reckoned in hundreds of thousands of kilometres, and to the planets in millions.

On Earth, only railway transport moves along definite lines, all other types of transportation constantly deviate from the geometrical line of the route (influencing factors are uneven roadways, movement of the wind and water, uneven engine operation, and many others). Not so the spaceship. Throughout the whole journey the only influencing factor is the Sun's attraction, and the ship moves along a strictly definite path, along invisible rails, as it were.

It would seem that there is no need to fear collision with a passing ship in the broad expanses of interplanetary space and that some deviation from the exact route is not so terrible after all. Yet cosmic flights require greater accuracy in control of the ship and more watchfulness than seafaring or air travel. The minutest deviation in velocity or direction is fraught with grave danger. This will be seen from the following examples.

In a minimum velocity take-off to the Moon, a cut in the speed of departure of one metre per second will reduce the range of the ship by 4,000 kilometres. The situation is still worse in planetary voyages, in which case a one-metre-per-second drop in speed produces a change of tens and hundreds of thousands of kilometres in range.

By way of illustration, suppose that we are leaving for Jupiter over a trajectory that requires a minimum take-off speed of 14,226 metres per second. If this speed is reduced by only one metre per second the ship will miss its destination by 400,000 kilometres. If the error in velocity
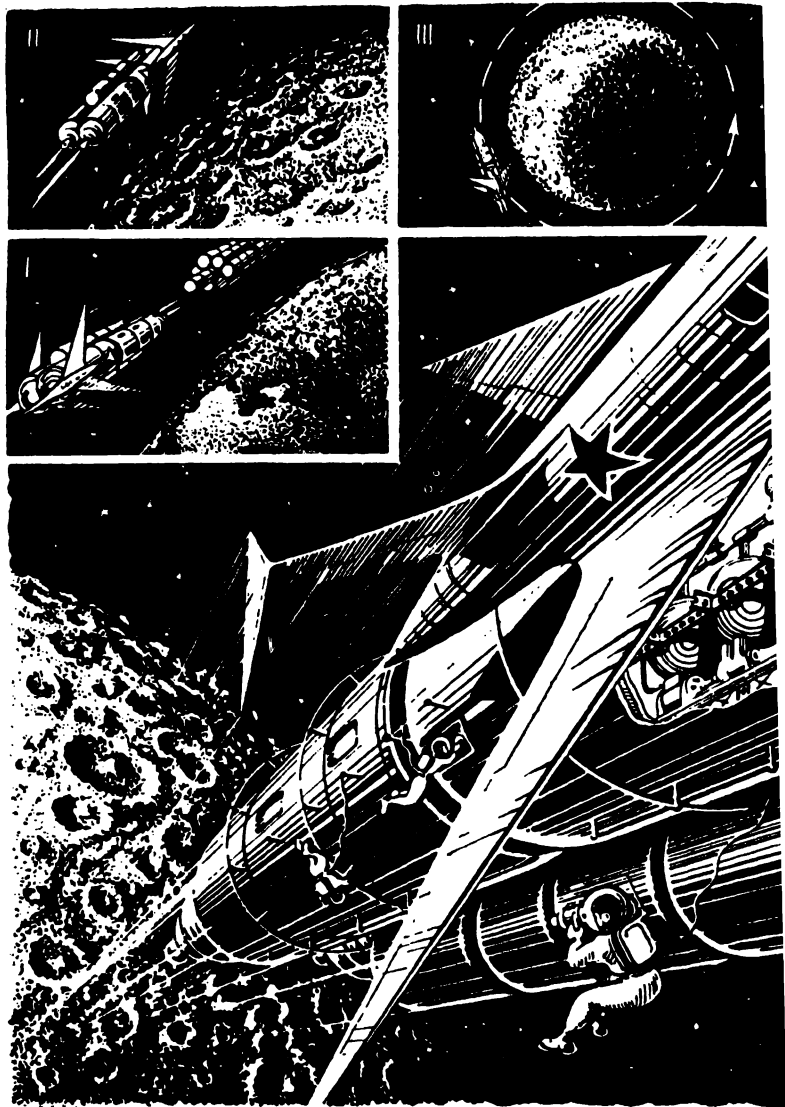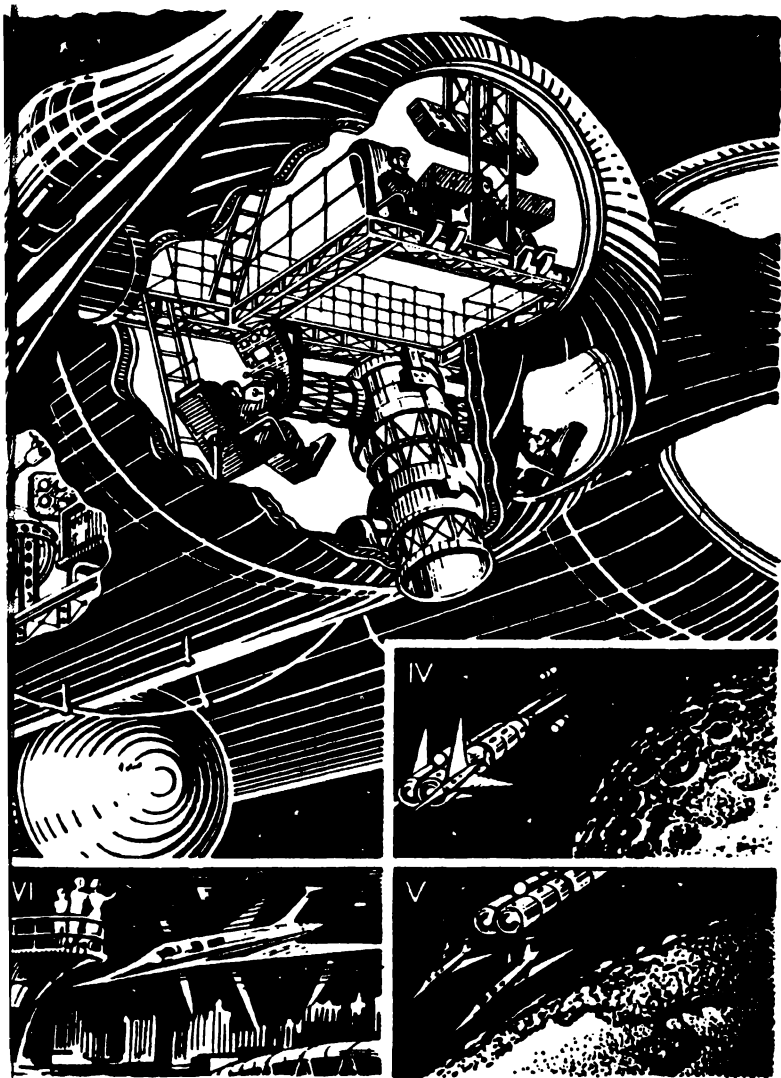
Fig. 25. Centre: Design of a spaceship for close-orbit exploration
becomes artificial satellite of Moon; III—The circumlunar orbit;
spaceship for descent to Earth; VI—Space

of the Moon. I—Take-off from an artificial Earth satellite; II—Ship
IV—Leaving the Moon; V—Gliders detach themselves from
gliders make final landing on Earth

is one-tenth of one per cent, the ship will miss the planet (either coming too early or too late) by something over 5 million kilometres. This is due to the fact that at great distances from the Earth or Sun the force of gravitation is not at all felt and the tiniest gain in speed greatly increases the range of the rocket. An angular deviation of one-tenth of one degree in the take-off can result in missing the objective by hundreds of thousands of kilometres.

Pilots will have to keep a constant watch over the ship's course and make corrections by means of a tiny rocket engine.

How will the distance covered by the ship be measured?

In a lunar voyage, this will be done by measuring the angle subtended by the Earth or Moon: the smaller the angle, the greater the distance. Distance from the Sun may be found by measuring temperature. Modern electric thermometers are capable of recording variations in temperature as small as one-millionth of a degree. They can be used to detect ship movements of only 2-3 kilometres with respect to the Sun.

3. Landing

How will a ship returning from a space journey land?

Theoretically, the rocket engine could be used for this purpose. A rocket engine switched round to fire in reverse would reduce the speed because the exhaust gases would thrust the rocket in a direction counter to flight. But a rocket is not capable of carrying the enormous quantities of fuel that this would require.

Air drag may be used to decelerate the ship. However the inevitable heating of a vehicle moving at cosmic speeds in the atmosphere cannot but give rise to misgivings. The example of meteors—"shooting stars"—that incinerate as they plunge into the atmosphere shows that the

landing on Earth of a vehicle from space is a complex problem. At any rate, parachutes do not appear suitable for decelerating space vehicles as they would burn up instantly. Besides, such retardation would be too sudden. And in general a cumbersome unstreamlined interplanetary ship is not suited to landing on the Earth. In its plunge through the atmosphere it would undoubtedly become white-hot.

And so the crew would transfer to a space glider of ideal streamline form just before going into the upper atmosphere of the Earth. The spaceship itself then faces two alternatives: either it burns up in the air like a meteor, or, if the engine is fired for a brief time, the ship will become an Earth satellite.

As the glider approaches the Earth at an 11 kilometre-per-second clip it grazes into the upper layers of the atmosphere and then pulls out again into empty space. In the air glider will shed some of its speed, and by repeating the process several times it will gradually reduce its speed considerably. This type of landing keeps the glider fairings from heating to a high temperature.

As the glider loses speed the surface area of its "rudimentary" wings becomes insufficient for gliding, so at this point retractile wings take over. The glider goes down into the denser layers of the atmosphere, and the whole landing procedure lasts several hours. Thus, gliding retardation is executed gradually so that the vehicle does not heat up and the temperature in the cabin does not rise too high. When the glider's air speed is nearly all lost it will land.

Similar is the return to Earth from an interplanetary station. In this case, a miniature rocket engine could be used to "fire" the glider at a small speed in a direction counter to that of the station. Having lost some of its speed it would make a gradual dive down through the atmosphere.

VI. SPACE FLIGHT

1. A Trip to the Moon

Undoubtedly the goal of our first flight into space will be our companion, the Moon, which is only 384,000 kilometres distant—100 times closer than the nearest planet Venus when the latter passes by the Earth. Even by terrestrial standards this is a relatively short distance. Many are the railway workers and sailors who have covered as much, and scores of pilots have flown far more kilometres than to the Moon and back again.

Man is capable of climbing the loftiest mountains. But would he have strength enough to reach the Moon if there existed an Earth-Moon ladder?

Numerous experiments have demonstrated that to reach a height of 1,550 metres takes a full workday. Now if the average distance between the Earth and the Moon were divided by what a "lunar climber" can do in one day we would find that to reach the Moon would take something like 680 years, if the conditions of the first day remained unchanged. But the point is that they wouldn't: since the force of gravity falls off with altitude it would be progressively easier to climb, and the rate would increase to such an extent that 11 years hence our "mountain climber" would have reached his destination.

Now how long would it take a rocket ship to reach the Moon?

With a take-off velocity of 11.2 km per sec., it would arrive in 51 hours.

Like the first Earth satellites, the first lunar rockets will probably be automatic. The path of such a rocket will be followed by the radio signals it will emit. Scientists will know either by radio signals or the flash of a light charge that the rocket has reached the Moon. The flash will be particularly easy to see on the dark part of the lunar disc. In addition, when the rocket hits the surface it can dis-

perse a white powder over an area large enough to be seen from the Earth.

Later, more powerful crew-carrying rockets will take off from a space station and become artificial lunar satellites, spinning about the Moon without expending fuel. This will make Moon studies very convenient.

Calculations show that with an exhaust velocity of 4 km per sec. a rocket weighing, say, 10 tons and taking off from an artificial satellite on a lunar mission will have to take along only 12 tons of fuel, whereas if the take-off were from the Earth's surface it would need 150 tons. With an exhaust velocity of 2.5 km per sec., the rocket would require 25 tons of fuel in the first case and 840 tons in the second. Besides, the fuel consumption needed to overcome air drag is left out of the account and it is assumed that the ship instantaneously reaches top speed.

Since observers on Earth always see only one side of the Moon, of great interest would be an exploration of its other, inaccessible hemisphere. A flight over this part of the Moon could be made when the latter is fully illuminated by the Sun's rays and consequently when it provides good seeing conditions for the astronauts. On Earth this corresponds to the period of New Moon.

It is to be expected that the averted face of the Moon is not essentially different from the hemisphere that we see and that it too is waterless and lacks anything in the way of a dense atmosphere. The travellers will look down on to the vast dark expanses of plains, so-called "maria," or "seas"; mountain ridges slashed by deep clefts; brilliantly lit mountain tops and their bases in jet-black darkness; the enormous ring-like and jagged bulwarks breaking off precipitously inside and gently sloping down on the outside (so-called "cirques"); and chains of craters.

Let us imagine a ship (see Fig. 25, I) taking off from a space station on a lunar exploratory mission.

During coasting flight the speed of the spaceship will vary. Like a stone thrown up it will gradually lose speed.

Five days later the ship will be in the Moon's field of gravitation and will again begin to gain speed. At a height of several tens of kilometres above the lunar surface it will be as much as 2.5 km a second.

To convert the ship into a lunar satellite at, say, 10 kilometres altitude, its speed must be reduced to 1.7 km per sec., which is the circular velocity for this height (Fig. 25, II). The orbital period of the satellite ship will be 1 hour 50 minutes, the distance to the horizon, 186 kilometres, and the minimum size of objects on the surface visible to the naked eye, 3 metres.

The ship can spin about the Moon for any length of time without using up fuel (Fig. 25, III).

For the return journey to Earth, the engines are turned on, and as the ship gains speed it works out of the circular orbit, leaving behind the detached fuel tanks that continue circling the Moon (Fig. 25, IV). These tanks could be equipped with automatic instruments that would at regular intervals transmit to the Earth by radio the results of measurements.

The ship would descend as described earlier (Fig. 25, V), and the landing of the space glider would be made with fully extended wings (Fig. 25, VI).

Following the circumlunar reconnoitring missions will come landing trips.

Will it be possible to land on the Moon without expending fuel? Has the Moon an atmosphere?

Observations show that the Moon's atmosphere is exceedingly tenuous. For this reason, it will not be used for braking purposes in descending to the surface. Instead, rocket engines will do the job.

Space travellers on the Moon (and this goes for all atmosphereless bodies) will have to stay in air-tight quarters, or venture outside only in special spacesuits just like on an artificial satellite. Despite this cumbersome dress, the astronauts will find no difficulty in moving about because the Moon's gravity is one-sixth that of the Earth.

To escape the lunar field one requires 20 times less energy than he would need to overcome the Earth's gravitation. Hence, the take-off speed towards the Earth is appreciably less than that required in leaving the Earth on a lunar mission: somewhat below 2.5 kilometres a second. Even simple-type (single-stage) liquid-fuel rockets are presently capable of developing such a speed.

2. Mission to Mars

A trip to Mars is of great interest. Astronomers and other scientists have been particularly interested in Mars because it is close to the Earth and has physical conditions very similar to ours.

A Martian landing mission will obviously be preceded (like the lunar trip) by exploratory flights around the planet. The rocket ships will temporarily become artificial Martian satellites. Indeed, during the first stages a mission with landing and subsequent take-off will encounter tremendous difficulties, especially as all the fuel for the return journey will have to be taken along from Earth. A detailed study of the Martian surface will make it possible to map out suitable regions for landing future expeditions. It will also enable us to collect data unattainable from terrestrial observatories, yet necessary before a landing mission to Mars can be attempted.

A first-priority task will be to establish whether the structure and composition of the Martian atmosphere can be used by spaceships to descend by air-braking. Such a study will likewise help us to find out whether this planet has a medium in which man can exist; and whether the Martian atmosphere is a sufficient shield against the numberless "falling stars" and harmful radiations that pierce interplanetary space.

Astronauts on Mars will be endangered by the Sun's ultraviolet rays, since the latter pierce right through

the ozone-poor Martian atmosphere to the planet's surface.

A trip around Mars can be made to follow trajectories that differ both as to duration and speeds that the ship will have to attain.

Let us take a flight path for a trip (including return to Earth) lasting two years (Fig. 26). The ship takes off from a space station at midnight (local time) when the centre
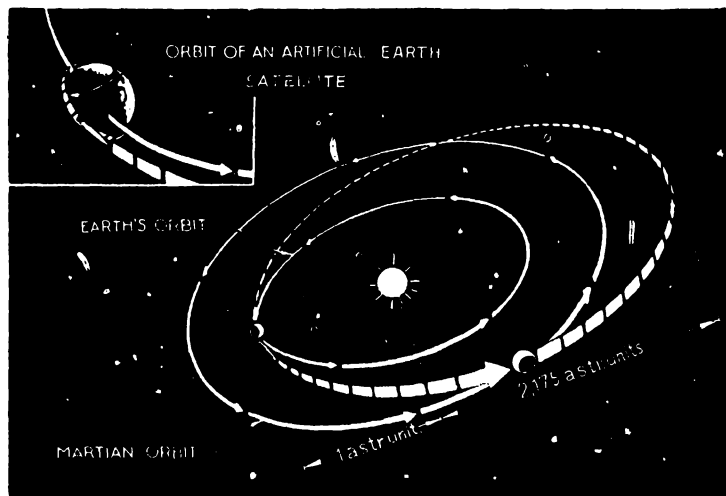

Fig. 26. A circumnavigation of Mars in two years. Top: rocket taking off from space station

of the Earth is on a straight line connecting the station and the Sun. This is the most opportune moment because the direction of motion of the rocket and the station coincide. Thus the rocket will be able to exploit the velocity of the station itself and start out with the lowest speed —4.3 kilometres per second, whereas a direct take-off from the Earth would require developing a speed of 12.3 kilometres a second.

A manned rocket ship weighing 10 tons, with an exhaust velocity of 4 kilometres a second, would have to take along 19.6 tons of fuel in departing from a space station, and 216 tons if launched from the Earth.

The speed of a ship in interplanetary space constantly changes. It is a maximum at take-off, but gradually diminishes with the distance from the Earth's orbit.

The ship will approach Mars at the predetermined distance and then fly on past it into deeper space. During the flight past Mars the astronauts will be able to photograph nearly the whole surface as the planet turns on its axis.

A year from the time of take-off the ship will reach the extreme point of its trajectory—2.175 astronomical units. Here its velocity will be a minimum.

The ship will then again begin to approach the orbit of Mars at a steadily increasing speed. But as it cuts across the Martian orbit a second time it will not encounter the planet. In exactly two years' time the ship will have closed its elliptical trajectory and returned to the Earth with its original speed.

More powerful rockets will be able to land on Mars' dwarf moons—Phobos and Deimos, from which extended investigations may be conducted. Deimos is 23,000 kilometres from Mars—1/17 the Earth-Moon distance, while Phobos spins round at 9,000 kilometres above Mars. These satellites circle about their mother planet at a racing speed, Phobos completing one circuit in about 8 hours and Deimos in 30 hours. They are tiny in size and mass and have negligible gravitational pulls; it will therefore be easier to land on them and then take off again than to visit the planet itself.

Judging from available astrophysical data it may be conjectured that on the surface of Mars man will find conditions more akin to what is customary at home than what any of the other planets have. It is highly probable that Mars has a vegetation. The Martian atmosphere apparently

contains oxygen and no gases that are injurious to human life. But the air is exceedingly tenuous even at the very surface of the planet. This will force our space travellers to live in hermetically sealed quarters where air pressure and temperature can be regulated. Spacesuits will have to be used on excursions outside. Man will probably also find water on Mars. The intensity of the solar radiation here is one half that on Earth and, correspondingly, the climate is far more rigorous.

What trajectories are to be regarded as economical for a landing expedition to Mars?

The shortest route between two points in space is a straight line. But, as a rule, the path of a spaceship cannot be straight. Just as the Earth's gravity curves the trajectory of a stone thrown at an angle, so the pull of the Sun bends the path of a ship in space. Naturally, if the rocket engines are kept working the flight path can be straightened out, but the consumption of fuel would be exorbitant. Only in the extreme case when flying directly towards the Sun (that is, along a "solar ray") its gravitational attraction would not distort the rectilinear trajectory of the ship. But to accomplish this would require an unthinkable loss of fuel since the ship would have to overcome the terrific velocity of the Earth as it races round the Sun—some 30 kilometres a second. This speed carries the ship astray in much the same way that a boat crossing a river is carried downstream by the current.

Still, let us assume that the trip to Mars is made over the shortest route. It would then take 85 days. But this would require accelerating the ship to 39 kilometres per second. Such a trajectory is obviously not suitable.

Now a ship taking off from the Earth along a semi-elliptical path would require a minimum acceleration. And the velocity that would have to be cancelled in a landing on the surface of the planet would also be a minimum. (Fig. 27).
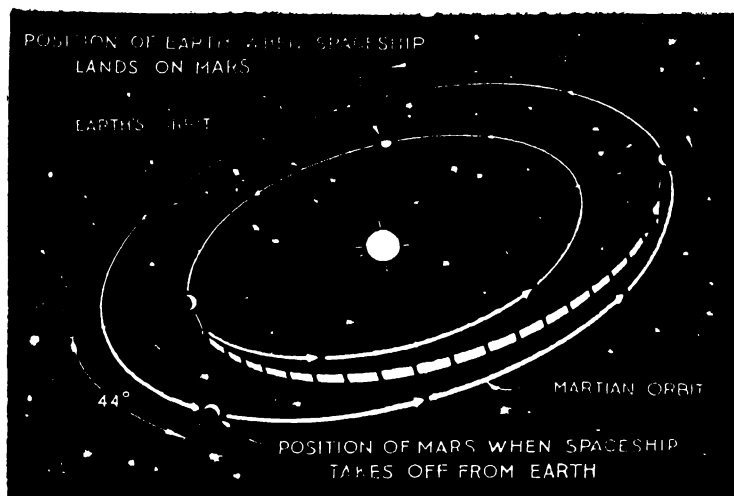
Fig. 27. A trip to Mars over a semi-elliptical trajectory

It was mentioned earlier that an interplanetary rocket with a definite route cannot take off at just any time. For a rocket to arrive at the Martian orbit and find Mars there, a definite Earth-Mars configuration is needed. These two planets get into such positions approximately every 780 days.

A trip to Mars over a semi-elliptical trajectory lasts 259 days. To make the return journey over the same path one would have to wait for another favourable configuration—due in 454 days.

A ship starting out for Mars over this flight path would have to develop a take-off speed of 11.6 kilometres per second. But future space travellers will hardly pick such a long route. They will probably try to cut transit time by increasing speed, making it possible to fly in, say, a parabolic trajectory. And if a speed of 16.7 kilometres per second is reached, the journey will last 70 days.

This is one of the remarkable peculiarities of space navigation: a 1.4-fold increase in the initial velocity cuts the duration of the mission by a factor of 3.7.

At the end of last century a view was current that intelligent beings existed on Mars. Numerous science-fiction novels were written on this theme and the authors did not restrict their heroes in selecting the time or the path of the journey. Yet in reality the problem is far more complicated. Only definite, "reasonable," routes are possible for trips from one planet to another. These routes correspond to very definite planetary configurations, thus also making the dates of possible take-off and arrival strictly limited.

If we draw up a schedule list of possible take-offs (destination: Mars or Venus, landing included), there will be breaks, "dead seasons," from several months to a year and a half and more during which no spaceship can rise from the Earth's surface or land at its destination because of an unfavourable configuration of the planets.

3. A Voyage to Venus

When the setting Sun at last vanishes below the horizon and we look into the darkening heavens above we see a particularly brilliant "star"—the planet Venus. Occasionally it makes its appearance just before dawn, and at times may even be visible in broad daylight. Venus' brightness is due to the fact that it is close to the Sun and reflects a good portion of the rays it receives.

Venus is not only our nearest planetary neighbour, it is more like the Earth than any of the remaining seven planets of the Solar System. Since its size and mass are only slightly less than their terrestrial counterparts, travellers on the surface should feel rather much "at home" as regards weight.

As far back as 1761, M. V. Lomonosov, telescopically, detected an atmosphere on Venus illuminated by the Sun.

For a long time it was thought that the Venusian clouds consisted of water vapour, which is a good reflector of the Sun's rays. But recent investigations of Venus' upper atmosphere have shown that there is neither water vapour nor oxygen present and that it contains a large quantity of carbon dioxide. This will make space travellers take along the necessary supply of oxygen for breathing.

Judging from observations made during twilight on Venus, the atmospheric pressure at the surface of the planet should be two or three times that on Earth. This will facilitate air-braking for spaceships with landing missions.

Opinions are not agreed on the rotation period of Venus: some workers believe it to be 68 hours; others take it equal to that of the Earth; and there is evidence indicating a period of rotation equal to the orbital period of the planet around the Sun, that is, 225 days. Still unestablished is also the angle of inclination of the equator of the planet to its orbit, and on this depends the variation of the length of day and night throughout the year.

It may be that only future explorers in a circumnavigation of Venus will be able to give all these problems a precise solution. With such data at hand, it will likewise be possible to determine the height and direction for spaceships to enter the Venusian atmosphere so as to make a safe landing, for the less the speed of the ship relative to the gaseous mantle of the planet, the easier and safer will the landing be. And this speed differs greatly depending on whether the rocket cuts into the atmosphere in the direction of the latter's axial rotation or counter to it.

The first exploratory expeditions will have to make a detailed study of the crust structure of the planet, and to determine whether it supports vegetation and animal life, and so forth. These observations are extremely difficult due to the thick cloud cover about Venus. However, using new photographic techniques in the invisible infrared rays

it will be possible, from a space vehicle, to take pictures of the surface right through the clouds.

Let us imagine ourselves aboard a ship en route to Venus (Fig. 28). After the 11.5-kilometre-per-second take-off from the Earth, the pilot has switched off the rocket engine and the ship is in coasting flight like a stone flung
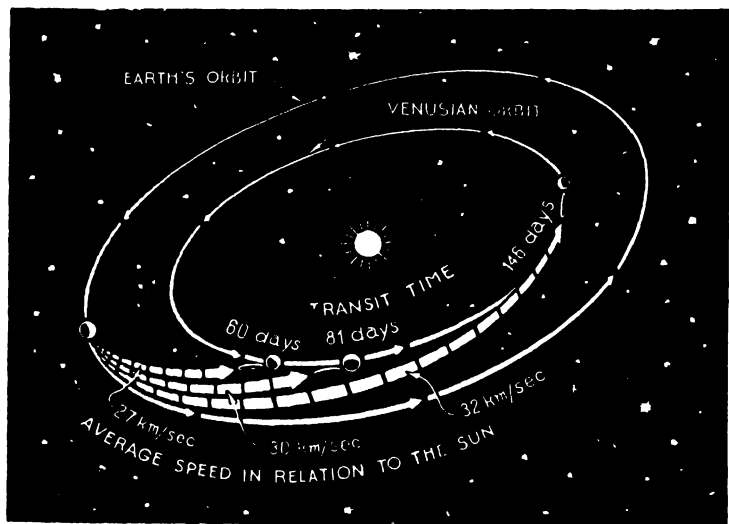

Fig. 28. Elliptical flight paths to Venus

from a sling. The sensation of weight has vanished and everyone rushes to the windows. Close by in black space there hangs a slowly rotating greenish-blue sphere—Earth. Through breaks in the clouds on the sunlit side of the Earth disc we easily discern the outlines of the continents. The ship has jerked itself loose of the Earth's gravitational field, and the distance between the planet and the spaceship increases.

Months pass. Our now remote Earth has long since become a bright bluish body in the heavens. The Sun's hot radiant breath is more and more felt. And through the

windows we see expanding a new, unknown world coruscating bluish-white in the distance—Venus. More and more stars are blotted out by its rapidly approaching disc. Velocities will have to be matched and the "brakes" put on, otherwise the falling ship will plunge into the planet like a giant meteorite, the kinetic energy passing into thermal energy and causing an explosion that would vapourize the metal and leave behind only a huge crater of what was once a ship.

But the pilot artistically escapes such a crash landing by grazing the Venusian atmosphere nearly parallel to the surface and utilizing the air resistance to gradually reduce the speed of the ship. The final braking is done by firing a tiny retarding rocket engine situated in the nose of the ship. Another few moments and, after a smooth retarding descent, the terrestrial ship "touches down" on the ground of our nearest neighbour planet.

The days rush by in a fever of observation making, experiments, specimen collecting, and other scientific work. And now at last the day of departure comes. At take-off the ship develops a speed of 10.7 kilometres a second and settles into a semi-ellipse, tangent to the orbits of Venus and the Earth. The entry into the Earth's atmosphere is made at 11.5 kilometres per second, but this speed is neutralized first in the higher tenuous air and then later in the denser layers.

The cosmic ship has brought back safely to Mother Earth her space travellers.

A trip to Venus over the above-described trajectory will last 146 days. But it can be reduced to, say, 81 or 60, or even less. In terrestrial conditions, the normal way to achieve this is by increasing the speed. But in space travel this is not always so. In our case, the higher the initial velocity of the ship with respect to the Earth, the slower it will move in space relative to the Sun, because it flies in a direction counter to the Earth's motion. Take a man running through the cars of a train in the opposite

direction to that in which the train is moving. The faster he runs the slower will his speed be relative to the Earth.

Then why, despite the lower velocity of the rocket in interplanetary space, is the voyage made in a shorter time?

The clue is given in Fig. 28. It may be seen that the distance the ship covers in each successive route variant is much shorter than in the preceding one. This makes it possible to cut the transit time notwithstanding lower flight speeds.

4. Journeys to Other Worlds

We described flight conditions to our three closest neighbours: the Moon, Venus, and Mars. Trips to the other planets of the Solar System will entail far greater difficulties.

As we have already seen, the take-off velocity from the Earth to other planets depends on the route, and from this viewpoint a semi-elliptical trajectory is most economical. What minimal velocities are required to reach the other planets of the Solar System and how long will such trips last?

The answer may be found in Table III.

And now, referring to Fig. 29, we see why a voyage to Mercury over a semi-elliptical route takes much less time than a trip to Venus, despite the fact that Venus comes closer to the Earth than Mercury. Though paradoxical at first glance, the Earth-Mercury route is shorter than the Earth-Venus trajectory.

The next planet outwards after Mars is Jupiter, which is several times farther from the Earth than Mars. Between Mars and Jupiter is a belt of numberless tiny asteroids that present a definite danger to space flight. Besides, parabolic velocity on Jupiter is some five times that on Earth, while the force of gravity is almost three times as great. This would be a drag on the movements of space travellers or would perhaps make impossible a stay on the planet. This is not all. There are also other obstacles such as low temper-

ature and poisonous gases. However, in time Jupiter will be explored from a space vehicle in orbit about the planet.

Travellers to Mercury will have to bear in mind that this planet turns on its axis in exactly the same time that it revolves about the Sun (88 days). The result is that one hemisphere of the planet is constantly exposed to solar radiation, while the other is in eternal darkness and extreme cold. On the borderline between them is a narrow
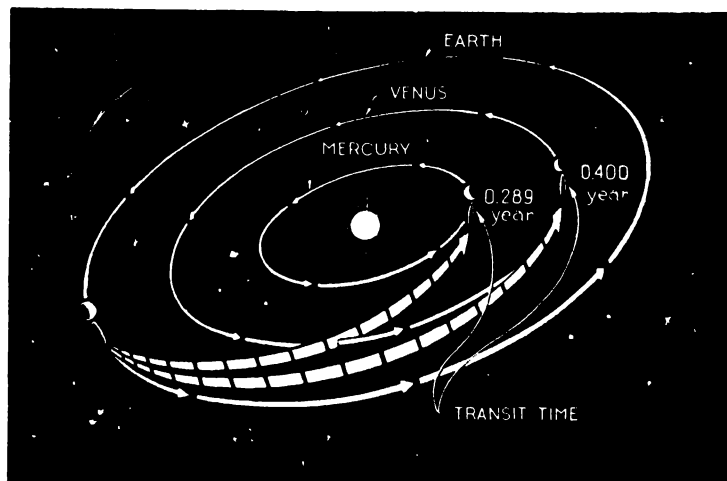

Fig. 29. A semi-elliptical route to Venus takes a longer time than one to the more distant Mercury

half-lit belt with a temperate climate. Incidentally, one may speak of Mercury's climate only in a figurative way because this planet is apparently devoid of any atmosphere.

The mean energy of the Sun's rays on Mercury is nearly seven times that on the Earth. The ground temperature on the sunlit hemisphere reaches 400 degrees Centigrade. This makes it imperative that the skin of a spaceship approaching this hot planet reflect into space the greater portion of the solar rays falling on it.

Apparently, the only way a landing on Mercury could be accomplished is by using the rocket engine, and this would complicate such a journey.

Trips to Saturn, Uranus, Neptune, and Pluto over paths requiring a minimum take-off speed would be too time-consuming. To reach these planets one would need super-power "express" rockets. For example, if we boost the take-off speed of a Pluto-bound rocket 5 per cent and leave the Earth with the velocity of escape from the Solar System (16.7 km/sec.), the transit time would be more than halved. The path of flight would then be the arc of a parabola, tangential (at its vertex) to the Earth orbit, with a focus at the centre of the Sun. The transit time of a trip over such a trajectory to the outer planets is given in the right-hand column of Table III.

Table III

Destination planet	Minimum take-off velocity, km/sec	One-way transit time		Take-off velocity, km/sec	One-way transit time	
		Years	Days		Years	Days
Mercury	13.5	—	105	—	—	—
Venus	11.5	—	146	—	—	—
Mars	11.6	—	259	16.7	—	70
Jupiter	14.2	2	267	16.7	1	39
Saturn	15.2	6	18	16.7	2	194
Uranus	15.9	16	14	16.7	6	282
Neptune	16.2	30	225	16.7	12	343
Pluto	15.3	45	149	16.7	19	91

Although the force of gravity on the trans-Martian planets (with the exception of Jupiter) is roughly that of the Earth, their natural conditions are not suitable as an abode for human life. The atmospheres of Saturn, Uranus, Neptune, and Pluto have been found to contain principally methane ("marsh gas") and the surface temperatures are extremely low.

What are the chances of flights to the nearest stars?

When we look at the heavens with naked eye or through a telescope we are not able to gauge the distance of these bodies from the Earth: both planets and stars seem to be equally remote. But in reality the distance between the planets and the stars is startling. From Pluto (the outermost planet of the Solar System), a ray of light (travelling at 300,000 kilometres per second) takes 7 hours to reach the Earth, while from the nearest visible star it "journeys" more than four years. This is why interstellar travel seems so much a thing of the remote future.

CONCLUSION

In this booklet we have made an attempt to give the reader a glimpse into the future of astronautics.

The efforts of Soviet scientists and technicians were crowned by the launching of the first artificial satellites of the Earth. This experience will be utilized to launch a whole series of large satellites equipped with progressively more complex and varied instruments; animals will be used to find out the hazards of flight on artificial satellites to living organisms; this will then be followed by the last stage—the building of artificial satellites of such size that they will accommodate both instruments and human beings.

The first artificial satellites will orbit the Earth in ellipses that are more or less close to the surface of our planet. Later, satellites will be given greater speeds and their orbits will stretch out into elongated ellipses.

During the initial stages big difficulties will be encountered in raising the "ceiling" of an artificial satellite, but the problem will be progressively easier to solve as the rocket power is increased. Recall that an increase in the initial velocity of a satellite vehicle from, say, 7.9 to 10 kilometres per second will raise its "ceiling" three equatorial radii, whereas an added 1 km/sec. would push up the "ceiling" to 25 Earth radii. Thus, a rocket with a velocity of 11 kilometres a second would be able to fly half-way to

the Moon. This will be followed by a circumnavigation of the Moon and our nearest planetary neighbours.

To reach the Moon and the planets of our Solar System a rocket will have to develop a velocity of the order of 11.1 to 16.7 kilometres per second.

Space stations will help to solve this problem. The initial velocity need not be imparted to the spaceship at once: at Earth take-off, the ship will be accelerated to circular velocity (about 7.9 km/sec.), then as it takes off from the space station it will be given another 3 to 4 kilometres per second.

Flights to the planets can be accomplished on chemically-propelled rockets. But the use of atomic energy will open up to astronautics new possibilities and atomic spaceships will eventually supersede the most refined chemical rockets.

Atomic rockets will make possible nonstop trips to the Moon and the planets. Braking on airless planets or satellites will be easily coped with by atomic rockets. An atomic ship will be able to make the return journey to Earth from any body of our Solar System. And, lastly, due to its great speed an atomic ship will be able to take off at any time without waiting for a favourable planetary configuration.

After its initial acceleration, the spaceship will continue its journey in coasting flight, thus saving fuel through the use of accumulated energy. For the same reason, spaceships, unlike other modes of transportation, will not follow a straight path. Their trajectories will be the arcs of ellipses and, later, parabolas and hyperbolas.

Before expeditions leave for the Moon and planets, these bodies will be explored by radio-controlled rockets, which will provide the data necessary for the building of spaceships. Likewise, the physiological conditions of space flight will first be tested on animals.

A single circuit about the Earth takes an artificial satellite just a little over one and a half hours. A trip around the Moon and back to Earth will last 10 days, while a

journey over an elliptical trajectory cutting the orbits of Venus and Mars and back again to Earth will take at least one year. Expeditions to the more distant planets will last several years.

Modern radio techniques are capable of maintaining contact with space vehicles. And since ships taking off into space will be subject to the very same laws as celestial bodies, it will be possible at any time to determine their position relative to terrestrial radio stations.

Physiologically speaking, there should, apparently, be nothing standing in the way of interplanetary travel. During the several-minute powered ascent of a rocket, the occupants should be able to withstand accelerations of four to five gravities, thus making it possible to reach cosmic velocity with the rocket engine working under sufficiently economical conditions.

As to weightlessness, we are not yet sure that its action on the human organism will be harmless over extended periods of time. But a negative result will not stop the conquest of outer space, because it is completely feasible technically to create a sensation of gravity by means of rotary motion.

The temperature inside the cabin may be regulated over a broad range by arranging for a more or less intensive absorption of the Sun's rays by the skin of the ship.

To establish in the cabin of a spaceship a micro-atmosphere of suitable composition and humidity and to supply the passengers with food and safeguard them against the Sun's ultraviolet rays is no problem to present-day technology. The problem of how cosmic rays affect the human body is presently under study. A grave danger is the possibility of meteor hits and encounters with asteroids.

Interplanetary travel will supply the answer to one of the most disturbing questions—is there life on the other planets of our Solar System, and if so, how developed is it?

Aside from its great scientific interest, interplanetary travel will obviously, in time, have a practical value, though at present it is hard to foresee the concrete shape it will take. It may be pointed out, for instance, that the planets and their satellites are tremendous storehouses of natural wealth which must be explored and utilized for the benefit of man.

The sole aim of the Soviet people, in the building of interplanetary stations and spaceships, is to delve deeper and deeper into the secrets of the Universe and to extend the power of man's intellect over the forces of nature.